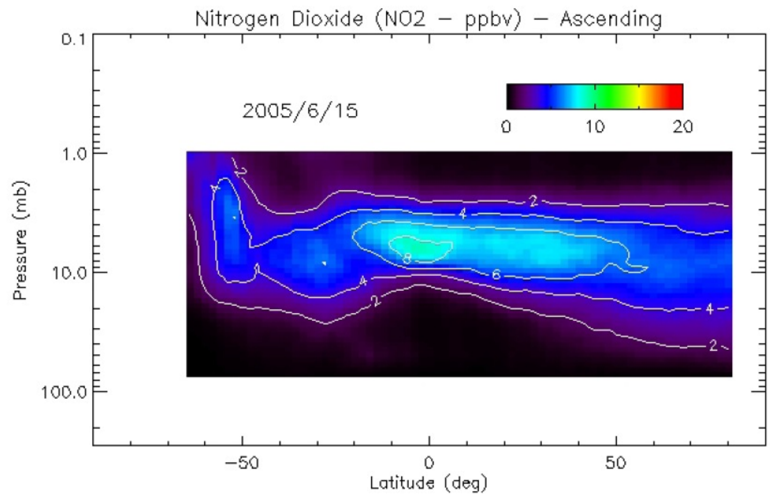
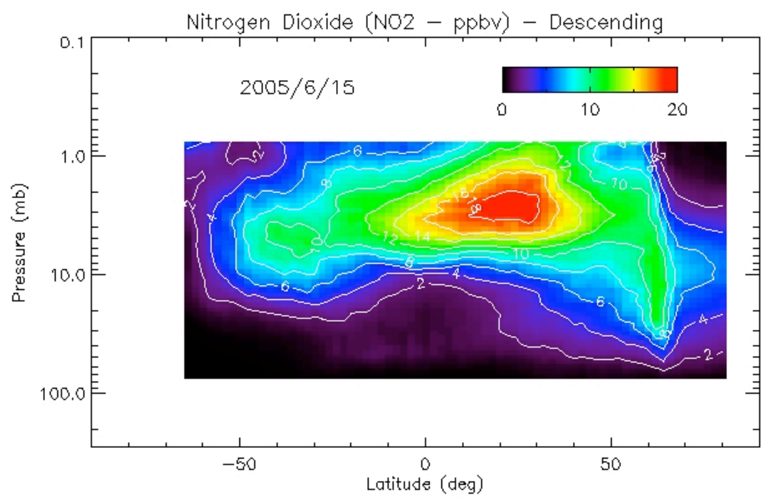
HIRDLS

High Resolution Dynamics Limb Sounder
Earth Observing System (EOS)
Data Description and Quality
Version 6 (V6)
(HIRDLS Version 6.00.00)
July 2011





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Cover Page:

Top Panel: Mean zonal NO_2 mixing ratio on the ascending orbit, mostly in daytime (~ 15:00LST). The HIRDLS scan track crosses the dividing line between night and day at ~ 50°S in the depth of the southern winter.

Bottom Panel: Mean zonal NO_2 mixing ratio on the descending orbit, mostly at night (~24:00LST). The scan track crosses the terminator from day to night at 65°N, forming a wall of high NO_2 mixing ratios that results from the fast $NO + O_3 \rightarrow NO_2 + O_2$ reaction.

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Information That Every HIRDLS Data User Needs to Know

I.1 Acquiring & Reading HIRDLS Level 2 Data

HIRDLS data are available from several worldwide data repositories. In the United States, HIRDLS data can be downloaded from the Goddard Earth Sciences Data and Information Services Center (GES DISC) (http://disc.sci.gsfc.nasa.gov/data-holdings). HIRDLS data are also available in the United Kingdom and Europe from the British Atmospheric Data Centre (BADC) (http://badc.nerc.ac.uk/browse/badc/hirdls). In both institutions, several versions of HIRDLS data are available and care should be taken to make sure that V6 data is requested.

HIRDLS data are stored in the HDF-EOS5 format in the HDF-EOS Aura File Format Guidelines (http://www.eos.ucar.edu/hirdls/HDFEOS_Aura_File_Format_Guidelines.pdf). These data files can be read via C/C++ or Fortran using either the HDF-EOS5 or HDF5 library. A HIRDLS developed IDL routine "get_aura" is also available upon request for those users who wish to use IDL to access the HIRDLS Level 2 (L2) data.

Warning for IDL users: Due to internal changes within the HDF5 library used to create V6 data, IDL must be upgraded to 7.1 in order to read the HIRDLS V6 data.

Users should obtain the pre-compiled HDF5 library for their operating system, if possible. Otherwise, source code is also available (see http://hdf.ncsa.uiuc.edu). These are prerequisite in order to compile the HDF-EOS5 library (see http://www.hdfeos.org/). Both libraries are needed to fully access the Aura HIRDLS data files. For additional help contact the GES DISC at help-disc@listserv.gsfc.nasa.gov or telephone 301-614-5224.

Level 2 Data Products

Each HIRDLS Level 2 file contains one day's worth of data for the L2 (profile) products listed in Table 1. The HIRDLS data are a set of values of temperature or mixing ratio on a set of 24 pressure levels per decade of pressure, uniformly distributed in log pressure (see Section 5.). The recommended pressure ranges for V6 are shown in Table 1. For users who require only a subset of the HIRDLS species, the GES DISC has the ability to subset data before distributing them to users. Contact the DISC directly for more information on this service.

Individual HIRDLS data values for a product are stored in fields labeled with the species name (see Table 1 for the exact names). The estimated precision of each data point is a corresponding field named *Species*Precision (for instance, Temperature and TemperaturePrecision). Two additional fields for each species, *Species*NormChiSq and *Species*Quality, are both filled with missing for V6. CloudTopPressure does not have Precision, NormChiSq or Quality fields. For V6 data, the fields for products other than those listed in Table 1 are filled with missing values (-999.0) since the radiance correction algorithms for these products are not mature yet.

There are two time fields in the HIRDLS Level 2 data file, Time and SecondsInDay. Time is stored in TAI time (seconds since the epoch of 00.00 UTC 1-1-1993). This time includes leap seconds and can cause problems with simplistic conversions. For this reason, HIRDLS is also storing SecondsInDay which is seconds since midnight of the data day. Leap seconds do not pose a problem when using this field. Note that the first data point may be negative which indicates a time stamp before midnight. This is the case for scans that span a day boundary.

Level 3 Data Products

As of V6, HIRDLS will be releasing new level 3 (L3) data products, created by applying a Kalman filter mapping algorithm similar to that described by Remsberg et al. [1990]. The algorithm inputs L2 retrieval results for a 2° latitude band for the length of the mission, and creates daily estimates of the zonal mean plus amplitudes and phases of the first six zonal waves using both forward and backward passes through the data (see Section 4.5). The means plus coefficients for a latitude may then be used to calculate values at any longitude. The algorithm also provides values for the precision, which is the root-mean square of the differences between the estimated fields and the input data. For the gridded data provided here results are generated every 2° of longitude, to create a 2° x 2° grid.

New products are zonal averages of daytime NO_2, zonal averages of nighttime NO_2 and N_2O_5, and gridded stratospheric column of daytime NO_2. These products are described in table M2 and Secs. 5.7, 5.8 and 6.0. The data file formats are described below.

Level 3 Zonal Average Files

HIRDLS is introducing a new zonal average data product with V6. These files are written using the HDF-EOS Zonal Average library. There are two files, each of which spans the entire HIRDLS mission; one contains the daytime NO_2, while the other contains the nighttime NO_2 and N_2O_5, with one set of latitude gridded values reported each day/night.

Level 3 Partial Column

The HIRDLS L3 partial column product is written using the HDF-EOS Grid library. This is described more fully in Section 6. This is a single file containing daily latitude/longitude grids of the partial column products. For V6, only the daytime NO_2 product is being released.

I.2 Data That Should Be Used With Caution

Level 2 Data Products

Data points for which most of the information comes from the a priori have their precision fields set negative, and the user should decide whether data are suitable for scientific studies.

See Khosravi et al., [2009a,b]; http://www.agu.org/journals/jd/jd0920/2009JD011937/ for details on quantitative a priori contributions to the errors. In addition, one may consult the document “Description of HIRDLS Predicted Precision Data”, available from the web page http://www.eos.ucar.edu/hirdls/data for details on negative precision.

HIRDLS data processing makes use of some Microwave Limb Sounder (MLS) data for contaminants. Because of the lack of full days of MLS data for 29 March-4 April (days 88-94) 2006, HIRDLS processing used data from NCAR’s Whole Atmosphere Community Climate Model (WACCM), driven by the GEOS5 meteorological data. These data are denoted by version v06-00-10. Although no anomalies in these data have been noticed, users should be aware of this.

Level 3 Data Products

The Kalman filter algorithm uses the L2 data plus estimates of covariance matrices and de-correlation times to generate estimates of zonal means and wave coefficients every day. The estimation process can continue even with little or no data. The number of points used to update the coefficients at each latitude are stored in the "DataCount" field. Users should be cautious of situations with small data count numbers, especially when conditions are changing rapidly. If this DataCount is negative, its absolute value indicates the number of days since (or before) measured data were input.

I.3 Known Problems

A few cloud tops are not detected, resulting in retrievals at low altitudes of cloud-contaminated radiances. This can result in retrieved temperatures being too warm, and positive or negative spikes in species retrievals.

HIRDLS scans across the limb in both directions, from space to Earth (down-scan) followed by a scan from Earth to space (up-scan). The two scan directions interact differently with the material blocking the optical train (Section 2.2), so different corrections for the blockage are used for the two scan directions. Every effort is made to make the two sets of results agree. While not expected, there may be some residual differences between up and down scans. Critical features in the data should be checked to ensure they appear in scans in both directions. Scan direction of a profile can be easily determined by examining the value of its ScanUpFlag in the HIRDLS2 file: 0 for down scan, 1 for up scan.

The ozone data show a slightly greater ozone amount on the ascending (day) segments of the orbit than on the descending (night) segment. The reason for this is not known. It is believed to be an artifact, and not a real effect.

Data from the period 3 January – 17 March 2008, when the chopper frequency was erratic, are provided, but the user should check them before using them. HIRDLS stopped acquiring data after 17 March 2008 when the chopper stalled.

V6 does not have a correction for high aerosol amounts near the tropical tropopause. This leads to spuriously high mixing ratio of CFC11 and 12, HNO_3 and perhaps temperature and some other species. Corrections are now being sought.

Table 1 below details the useful vertical range, estimated accuracy, and the HIRDLS team contact for each product in this version. The vertical range and accuracy entries generally summarize complex variations, and the listed references, or the web page http://www.eos.ucar.edu/hirdls/, should be consulted before any use of the data. Additional products may be available in future versions.

Table I-1: Information concerning V6 HIRDLS standard L2 products

Product	Field Name	Useful Range	Estimated Accuracy	Contact Name	Contact Email
Temperature	Temperature	1000 – 0.01 hPa*	± 2 K	John Gille	gille@ucar.edu
O_3	O3	422 – 0.1 hPa	† 1-10% <100ppbv UTLS	Bruno Nardi	nardi@ucar.edu
HNO_3	HNO3	215 – 7.5 hPa	† 5% to > 25%	Bruno Nardi	nardi@ucar.edu
Cloud top pressure	CloudTopPressure	422 - 10 hPa	± 20%	Steven Massie	massie@ucar.edum
12.1 Micron Extinction	12.1 Micron Extinction	215 – 20 hPa		Steven Massie	massie@ucar.edu
CFC11	CFC11	316 - 26.1 hPa	† 10% to >15%	Bruno Nardi	nardi@ucar.edu
CFC 12	CFC12	316 - 10.0 hPa	† 10% to >25%	Bruno Nardi	nardi@ucar.edu
GPH	GPH	1000 – 0.01 hPa*	2%	Lesley Smith	lsmith@ucar.edu
HDF5, HDF-EOS5	Library Installation			GSFC DAAC	Help-disc@listserv.gsfc.nasa.gov
HDF-EOS5	Reading HIRDLS Data			Vince Dean	vdean@ucar.edu

* A priori >383 hPa

† Varies with latitude and altitude.

Table I-2: Information concerning V6 HIRDLS standard L3 products

Product	Field Name	Useful Range	Estimated Accuracy	Contact Name	Contact Email
Zonal Mean NO_2 (day)	NO2Day	56.2 – 1.0 hPa	†~10-30%	Maria Rivas	rivasm@ucar.edu
Zonal Mean NO_2 (night)	NO2Night	56.2- 0.75 hPa	†~10-30%	Maria Rivas	rivasm@ucar.edu
Zonal Mean N_2O_5 (night)	N2O5Night	56.2 – 5.1 hPa	†~10-30%	Maria Rivas	rivasm@ucar.edu
Stratospheric Column Daytime NO_2	NO2DayColumn	N/A	†~10-30%	Maria Rivas	rivasm@ucar.edu

† Varies with latitude and altitude.

Note that the following references refer to the V3 data, but the descriptions of the data and the methods of evaluation are still applicable. In addition, one may consult the web page http://www.eos.ucar.edu/hirdls/ for more recent information.

Gille et al., [2008], The High Resolution Dynamics Limb Sounder (HIRDLS): Experiment Overview, Results and Validation of Initial Temperature Data, *Journal of Geophysical Research*; doi:10.1029/2007JD008824.

Khosravi, R., et al., [2009a]; Overview and characterization of retrievals of temperature, pressure, and atmospheric constituents from the High Resolution Dynamics Limb Sounder (HIRDLS) measurements, J. Geophys. Res., 114, D20304, doi:10.1029/2009JD011937.

Khosravi, R., et al., [2009b]; Correction to ''Overview and characterizati7/17/2011on of retrievals of temperature, pressure, and atmospheric constituents from High Resolution Dynamics Limb Sounder (HIRDLS) measurements,'' J. Geophys. Res., 114, D23399, doi:10.1029/2009JD013507.

Kinnison et al., [2008], Global Observations of HNO3 from the High Resolution Dynamics Limb Sounder (HIRDLS) – First Results, *Journal of Geophysical Research*; doi:10.1029/2007JD008814.

Massie et al., [2007], Validation of HIRDLS Observations PSC's and Subvisible Cirrus, *Journal of Geophysical Research*; doi:10.1029/2007JD008788.

Nardi et al., [2008], Validation of HIRDLS Ozone Measurements, *Journal of Geophysical Research*; doi:10.1029/2007JD008837.

-End of Information That Every HIRDLS Data User Needs to Know -

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* Not Contained in V6

1.0 Overview

1.1 Introduction

As the following sections describe, the entrance aperture of the High Resolution Dynamics Limb Sounder (HIRDLS) was largely obscured by a piece of plastic material that came loose during launch. This resulted in a partial blocking of the signal from the atmosphere, and the addition of extraneous signals from the plastic blockage material. Because of the position of the blockage, coverage of Antarctica and the higher longitudinal resolution expected are precluded, although latitudinal resolution has been increased, and vertical resolution maintained.

The HIRDLS team has been working since the discovery of this anomaly to understand the nature of the blockage, and to develop four major correction algorithms to make the resulting radiances as close as possible to those originally expected. Corrections for some channels, and therefore the products retrieved from them, are more advanced than for others. This had led us to release the current group of retrieved data products. This document provides a description of the fourth fully-released version of data for the entire mission, which includes retrieved temperature, ozone, nitric acid, chlorofluorocarbons (CFC) 11 and 12, geopotential height, zonal means of day and night NO_2 and night N_2O_5, stratospheric columns of daytime NO_2, and aerosol extinction, as well as cloud top pressure.

Work is continuing to improve the radiances, and the retrievals, for these channels, as well as for those channels whose products are not included in this release.

These data are scientifically important, but it is recognized that they will be improved in future versions. Some of the known problems with the data are described below, but these are almost surely not the only ones. This work is ongoing, and further improvements are being developed and implemented. The HIRDLS team is releasing these data for scientific use and validation, with the expectation that those who look at the data will provide feedback on deficiencies that need to be addressed in future versions, as well as strengths of the data. This document will be updated as additional data products are released, and as other changes dictate.

The information needed by a HIRDLS data user is presented in Section I (Information That Every HIRDLS Data User Needs to Know) at the front of this document. We strongly suggest that anyone wishing to work with the data contact the HIRDLS team. In the first instance, this should be one of the Principal Investigators (PI's):

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l.gray1@physics.ox.ac.uk

2.0 The HIRDLS Experiment

2.1 The Experiment as Designed

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine temperature; the mixing ratios of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, $ClONO_2$, Geopotential Height (GPH), and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals were to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

HIRDLS performs limb scans in the vertical, measuring infrared emissions in 21 channels ranging from 6.12 to 17.76 μm. The retrieval uses measurements of the emitted radiance by CO_2 in four channels with knowledge of the known (and increasing) mixing ratio of CO_2 to calculate its transmittance. Inversion of the equation of radiative transfer leads to determination of the vertical distribution of the Planck black body function, from which the temperature is derived as a function of pressure. This temperature profile is used to calculate the Planck function profile for the trace gas channels. The measured radiance and the Planck function profile are then used to determine the transmittance of each trace species and its mixing ratio distribution.

The overall measurement goals of HIRDLS were to observe the global distributions of temperature, the 10 trace species and particulates from the upper troposphere into the mesosphere at high vertical and horizontal resolution. Observations of the lower stratosphere are improved through the use of special narrow and more transparent spectral channels.

2.2 The Launch-induced Anomaly

2.2.1 History and Present Status

HIRDLS was launched on the EOS Aura spacecraft on 15 July 2004. All steps in the initial activation were nominal until the initialization of the scanner on 30 July 2004 indicated more drag than anticipated, and a subsequent health test of the scan mechanism indicated that the damping of the elevation mechanism was ~ 20% greater than on the ground. After the cooler was turned on and the detectors reached their operating temperature (~61 K), initial scans showed radiances much larger and more uniform than atmospheric radiances, except for a region of lower signals at the most negative azimuths. The HIRDLS team immediately identified this as indicating a probable blockage of a large part of the optical aperture.

Tests confirmed that the blockage emits a large, nearly uniform radiance, and covers all of the aperture except a small region 47° from the orbital plane on the side away from the sun.

A number of scan mirror and door maneuvers were conducted in an attempt to dislodge the obstruction, now believed to be a piece of plastic film that was installed to maintain the cleanliness of the optics. None of these maneuvers was successful in improving HIRDLS' view of Earth's atmosphere.

However, these studies and subsequent operations of the instrument have shown that, except for the blockage, HIRDLS performed extremely well as a stable, accurate and low noise radiometer. These qualities have allowed the HIRDLS team to develop methods for extracting the atmospheric radiance from the unwanted blockage radiance and to retrieve all of the desired species, although not all of them are of sufficient quality to be released at this time. This will allow HIRDLS to meet a significant fraction of the original science objectives.

Data are presented from 28 January 2005 until 2 January 2008, although occasional periods are missing when running non-science scans. There are some data between 21 and 28 January 2005, but the instrument had not yet settled into a stable state, and the data are of substandard quality. In addition, some data from the period 3 January – 17 March 2008, when the chopper frequency was erratic, are provided, but the user should be careful in using them. HIRDLS stopped acquiring data after 17 March 2008 when the chopper stalled. Efforts to restore it to operation have so far been unsuccessful.

2.2.2 Impact of Loss of Azimuth Scan Capability

In its present configuration, HIRDLS can view past the blockage only at the extreme anti-sun edge of the aperture. Vertical scans are made at a single azimuth angle of 47° line of sight (LOS) from the orbital plane, on the side away from the sun. (This differs from the original design, in which HIRDLS would have made vertical scans at several azimuth angles, providing orbit-to-orbit coverage with a spacing of ~ 400-500 km in latitude and longitude.) The inability to make vertical scans at a range of azimuths is a definite loss in data gathering, but not a major loss of scientific capability for many of the mission goals. Some of the effects of the present observing characteristics are:

Changes in coverage

The single-azimuth coverage is plotted in Figure 2.1, which shows that coverage only extends to 63.4°S, thus missing all of Antarctica and the S. Polar cap. In the Northern Hemisphere (N.H.) it reaches 80° N. In mid-latitudes of the N. Hemisphere, the descending orbit views nearly the same orbit at midnight as the ascending orbit at 3:00pm, 9 orbits or 15 hours later, as shown by the measurement times displayed in Figure 2.2

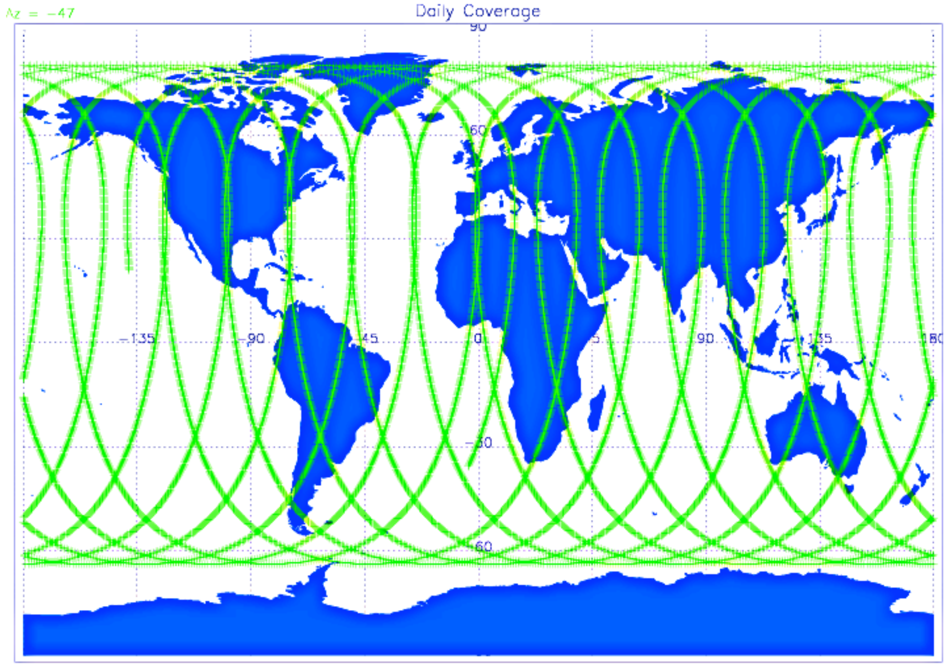


Figure 2.1 HIRDLS Single Day Coverage

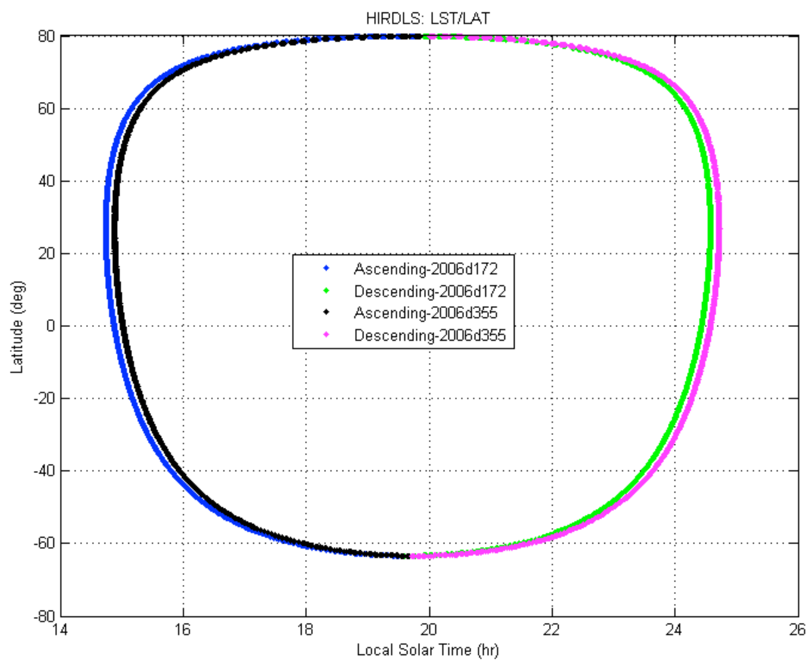


Figure 2.2 Local time of HIRDLS observations for the solstices, as a function of observing latitude

Inability to View the Same Air Mass as MLS, TES or OMI Within 15 Minutes

The HIRDLS scan track is compared with the MLS scan track in Figure 2.3. HIRDLS views nearly the same volume as MLS at night (descending part of orbit, left side of figure), but one orbit earlier. Thus HIRDLS views the same volume 84 minutes earlier than MLS (one orbit, or 99 minutes, minus the 15 minutes that separate MLS views ahead of the S/C and HIRDLS measurements behind the S/C). In the daytime (ascending part of orbit, right side of plot), HIRDLS observations fall 17° to the east of the MLS track in the same orbit, or 8° to the west of the MLS track in the previous orbit. Especially in the daytime, this difference impacts making comparisons, the planning of correlative measurements, and the opportunities to do combined science. However, comparisons and science can easily be done at night where desired.

A corollary feature is that, in the daytime, HIRDLS and MLS combined observe more longitude at a given latitude, which will improve the spatial resolution. At night, together they look at the same volume 84 minutes apart, increasing the temporal resolution.

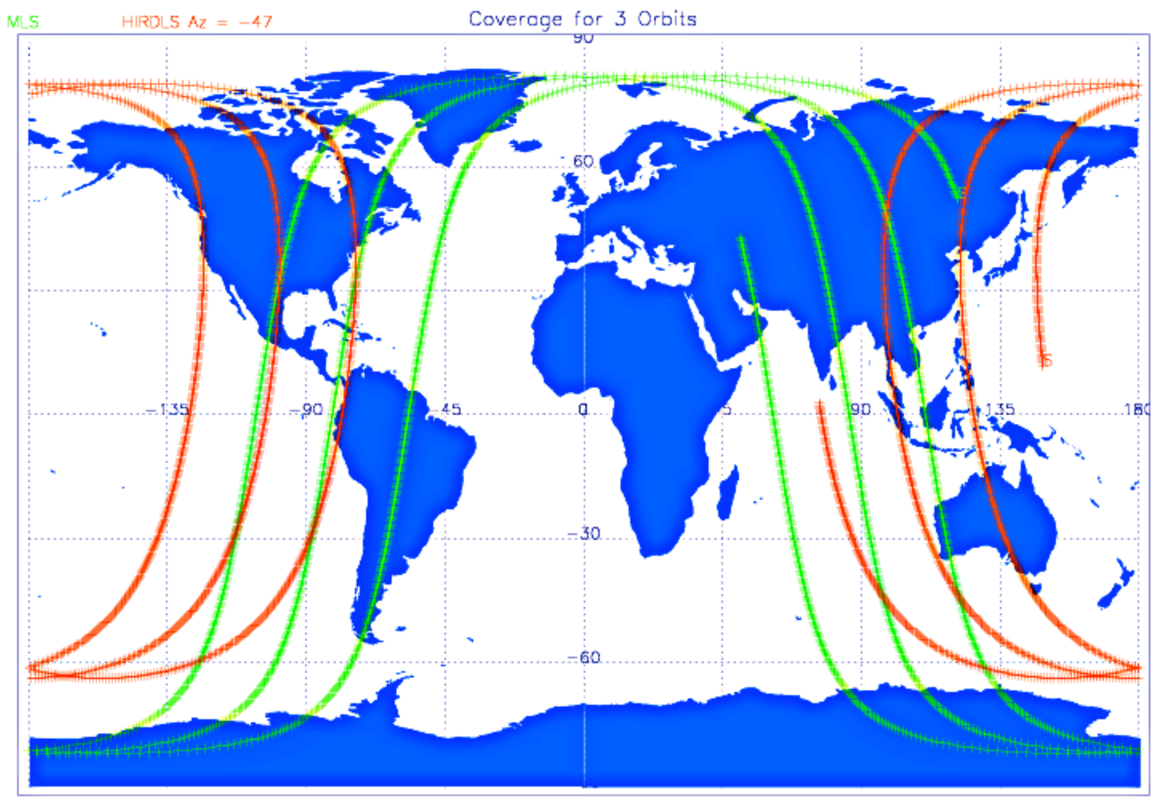


Figure 2.3. Comparison of 3 orbits of HIRDLS (red) measurement locations to MLS (green). HIRDLS is measuring the atmosphere at one azimuth angle (i.e., -47° from the orbit plane). The day and night portion of the orbits are on the right and left side of the figure respectively. During the day part of the orbit, HIRDLS is trailing MLS by one orbit (99-minutes). During the night part of the orbit, the spatial coincidence is much better, although HIRDLS leads MLS by one orbit.

Some compensating effects

With the azimuthal limitation, the profiles will have closer latitudinal separation (corresponding to ~100 km along track spacing), facilitating gravity wave studies. Transects through tropospheric intrusions into the lower stratosphere and tropopause folds are improved by continuous views at one azimuth.

Since HIRDLS views a long way off the orbital track, as seen above, it measures at a different local time from MLS, the Tropospheric Emission Spectrometer (TES) and the Ozone Monitoring Instrument (OMI), which are all flying on Aura. At the northern and southern extremes it means that HIRDLS will get data at a significantly different local time from the other instruments, which could help constrain data assimilation models.

3.0 Revised Operational Scan Patterns

The limited angle at which HIRDLS can see the atmosphere necessitates a revision to previously planned scan patterns. Scans of the atmosphere are done in the region in which the view of the atmosphere is the clearest, at -23.5° azimuth shaft angle, or -47° LOS from the orbital plane (on the side away from the sun).

Science Scan Modes

Scan Table (ST) 30 (21 January 2005-28 April 2005). This initial scan used a more rapid vertical scan speed, which generated larger amplitude spurious oscillations in the signals. Because of the difficulty in completely removing these, data from this period are not as good as later data obtained with the other scan tables. This scan also made vertical scans at a LOS azimuth angle of -44.8°, which were found to be inferior to those at -47°.

Scan Table 13: (28 April 2005 - 24 April 2006). Upper and lower limits of scans vary around the orbit, following Earth's oblateness. This was discovered to cause different types of oscillations to be seen in the signals, complicating attempts to remove these artifacts.

Scan Table 16: (26 October 2005, 1 & 2 November 2005, 21 & 22 February 2006, 16 April 2006). Same vertical scan speed as ST 22 & 23, but with greater space-ward and Earth-ward limits. Similar scan pattern as ST 30, with vertical scans at LOS azimuth angles of -44.8 and -47.0.

Scan Table 22: (25 April 2006 to 3 May 2006) Similar to ST 23, but with lower space-ward limit on the scans.

Scan Table 23: (Used since 4 May 2006) It makes slower vertical scans; 27 pairs of vertical up and down scans of ~ 15.5 seconds duration each, followed by a 1-2 second space view before the next 27 scan pairs. To facilitate removal of the oscillations, the space-ward and earth-ward limits of the scans are at fixed elevation scan angles.

4.0 Processing HIRDLS Data

The modified science scans described in Section 3 and the need to account for blockage of the scene and radiance from the blockage require substantial modifications to the operational data processing. A diagram of the flow of data in the HIRDLS processing is shown in Figure 4.1.

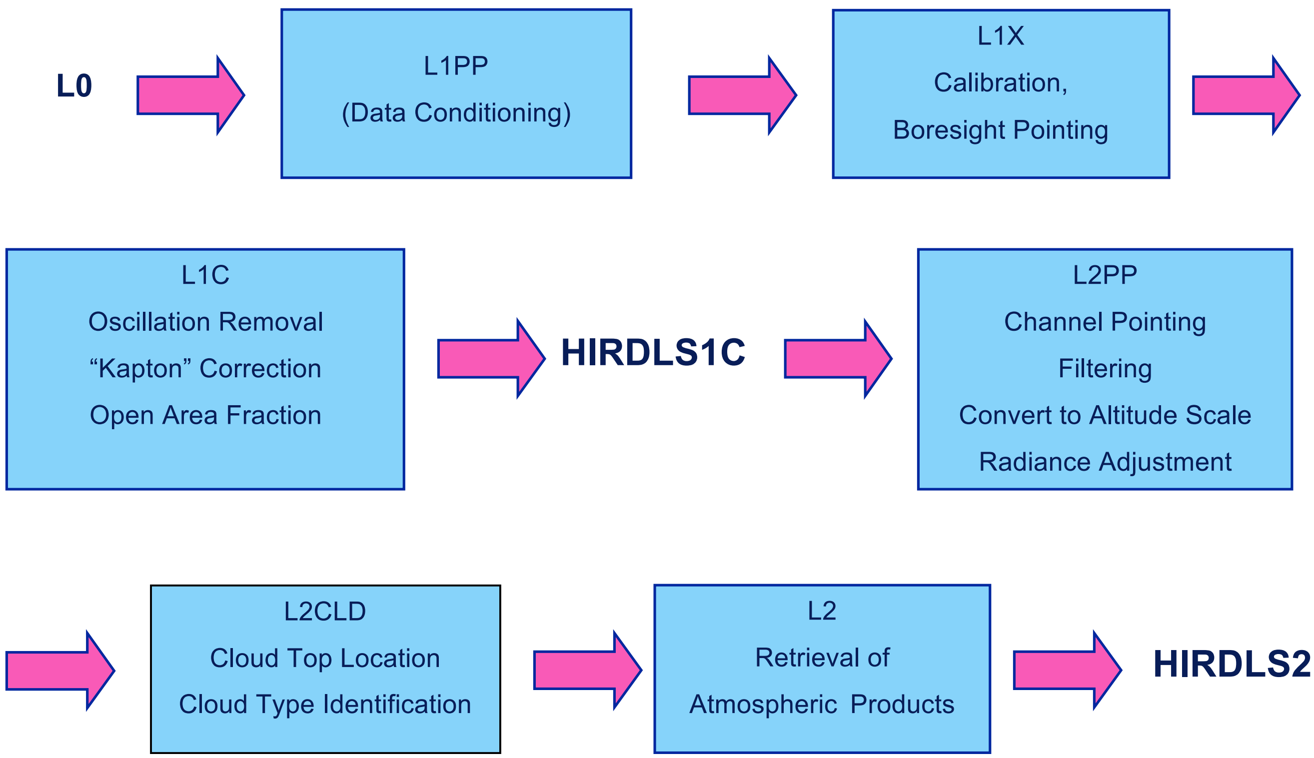


Figure 4.1 HIRDLS Processing Flow Through L2

4.1 L0-1 Processor (L1PP, L1X, L1C)

In the L0-1 suite of processors, the Level 1 Pre-processor (L1PP) corrects an occasional problem with the time in Level 0 (L0) data (raw data counts) while Level 1 Excellorator (L1X) carries out the modified calibration and geolocation. The Level 1 Corrector (L1C) applies the 3 main correction algorithms to remove the effect of the blockage that are outlined in Gille et al., [2008], and some recent work described in Gille et al., [2010]. Overall, the L0-1 processor creates a time series of calibrated radiances blocked into profiles as well as housekeeping data necessary to the further data processing.

4.2 L2 Pre-processor (L2PP)

The L2PP process takes the time series of radiance profiles from L1, separates it into individual geolocated vertical scans, determines the vertical registration in altitude, and performs low-pass filtering to condition the radiances for retrieval by the L1-2 software.

4.3 L2 Cloud Detection (L2CLD)

The L2CLD routine screens for clouds based on detection of radiance perturbations from the average clear sky case in channels 6 and 12. Cloud tops are located and identified.

4.4 L1-2 Processor (L2)

The L2 step accepts the conditioned radiance data from the L2CLD, and performs the retrievals through a series of iterations. This code is designed to be flexible in handling combinations of radiance channels to retrieve the HIRDLS target species in a user-defined sequence. One of the major features is the use of ancillary data from the Goddard Earth Observing System Model (GEOS-5), produced by NASA's Global Modeling and Assimilation Office (GEOS-5) to determine temperature gradients along the line of sight, which are incorporated to yield an improved retrieval. This processor is described in detail in the L1-2 Algorithm Theoretical Basis Document (ATBD) available on the web at http://www.eos.ucar.edu/hirdls/docs/atbds.shtml. GEOS-5 version 5.01 data were used through January 2, 2008, after which version 5.1 data were used.

From 4-18 December 2007, there were problems with the spacecraft data system, resulting in some corrupted data products. Subsequently the input data were reconstructed by the NASA ground data system, and reprocessed in the HIRDLS Science Investigator Led Processing System (SIPS). We are not aware of any resulting undetected problems at this time, but users should scrutinize these data carefully.

4.5 L2-3 Processor (L3)

The L3 processor is a Kalman filter used as a sequential estimator that combines weighted data from a single profile with a weighted estimate based on the previous data, as described by Rodgers [1977, 2000], Kohri [1981], and Remsberg et al. [1990]. In this process each data point is used to update estimates of the zonal mean and coefficients of the sine and cosine coefficients of the first 6 zonal waves (13 values, equivalent to the mean plus amplitudes and phases of the first 6 zonal waves). This is done for each pressure level and zonal band going both forward and backward in time, and the results are combined, thus ensuring smooth time evolution. Values are output at one time of day, resulting in daily values of the estimated quantities every 2° in latitude. This produces an optimal estimate of the state of the system in this representation. In general the final estimated field will not go through the input points, but will have an rms difference from them, termed the precision, approximately equal to the precision of the single profile observations. The output data includes this rms value, as well as the values from each of the diagonal elements of the covariance matrix that give the predicted variance of each of the estimated quantities. The output data also includes the number of points that went into producing the estimate for that day. Since the Kalman estimator produces estimates even in the absence of data, a negative number of points indicates the number of days without data since (or until) a day with data. For the present data, only the zonal means are used for day and night NO_2 and night N_2O_5.

For gridded data, the coefficients are used to calculate values every 2° in longitude, creating a 2° x 2° grid. In V6 this is used at each level for daytime NO_2. Stratospheric columns are obtained by integrating vertically at each grid point, resulting in a daily map of stratospheric columns of daytime NO_2.

5.0 HIRDLS Standard Products

Comments common to all products:

Vertical Range

The radiance measured by limb viewing instruments generally decreases as altitude increases, since there are fewer emitting molecules along the path through the atmosphere. The level where the signal to noise ratio (S/N) becomes of order 1 generally sets the approximate upper limit of useful retrievals. Gases with smaller mixing ratios at all levels, will in general have lower top altitudes.

For those gases whose distribution has a layer structure in the stratosphere, the fall to low mixing ratios at and below the layer peak may also lead to low S/N, and no useful retrievals at low altitudes. For species with mixing ratios that fall with altitude, the lower boundary will be reached either when a cloud intercepts the ray path from the tangent point to the detector, or where the channels become optically thick, so that no radiance reaches the detector from the geometric tangent level.

Vertical Resolution

The vertical resolution is shown by the full-width at half-maximum (FWHM) of the averaging kernels. These are presented for the different products in paired panels, with the averaging kernels on the left, and the FWHM on the right. Typically these are very close to 1 km over the range of interest.

The left panel also shows the sum of the averaging kernel values at a given tangent altitude. Values ≈ 1 indicate that all of the information is coming from the measured radiances, with little effect of the a priori values. Because of the low noise of the HIRDLS measurements, this is usually the case over the ranges of interest.

HIRDLS Pressure Levels

HIRDLS data are provided on 24 levels per decade of pressure, uniformly distributed in the logarithm of pressure, resulting in spacing that is consistent with the vertical resolution. The levels in a typical, 1 to 10 hPa, are listed in Table 5.1. Other pressures are these values multiplied by powers of 10.

Table 5.1: HIRDLS Pressure Levels for the Decade of Pressure 1 – 10 hPa

HIRDLS pressures in other decades are these values multiplied by powers of 10.

1.	
1.10069	3.481
1.212	3.831
1.334	4.217
1.4677	4.642
1.616	5.109
1.778	5.623
1.957	6.190
2.154	6.813
2.371	7.499
2.610	8.254
2.873	9.085
3.162	10.00

Precision

There are 2 measures of precision of the HIRDLS products. The L2 retrieval, which uses the Rodgers Maximum A-Posteriori Likelihood method [Rodgers, 2000], calculates an expected uncertainty of the retrievals based on the uncertainties of the input parameters (Khosravi et al., [2009a, b]), http://www.agu.org/journals/jd/jd0920/2009JD011937/).
These are referred to here as the predicted uncertainties.

As described in section 1.3, the predicted precision values are flagged as negative when most of the information in the retrieval comes from the a priori. Details regarding negative precision and an example of how to assess the a priori's contribution to the retrievals are given in Khosravi et al., [2009a,b].

We also estimate the precision from the variability of the retrieved products; this is referred to as the measured precision. These values are derived from an analysis of the variability in a set of multiple consecutive adjacent scans. The precision is estimated as the standard deviation of 12 consecutive profiles taken in a ~3 minute window over about 1100 km, roughly equivalent to 10 degrees latitude. The set of values at each pressure level is de-trended with a linear least squares fit in order to remove any effect introduced by mean gradient with latitude. We have looked at all data in a day, and taken the mean of the 10 smallest values. The standard deviation may still include some level of geophysical variability and is therefore an upper limit to the precision. The actual precision will be ≤ the standard deviation given here.

Accuracy

Because of the aperture blockage, it is not possible to do a first principles estimate of accuracy by the propagation of calibration and instrument characterization errors. We have taken the approach of comparing the HIRDLS products with results from conventional methods, or well-validated satellite data sets. These are the results presented here.

5.1 Temperature

Species:	Temperature
Data Field Name	Temperature
Useful Range:	1000 – 0.01 hPa* *A priori for pressures >383 hPa
Vertical Resolution	1 Km
Contact:	John Gille
Email:	gille@ucar.edu
Validation paper (V3)	Gille, J., et al., [2008], High Resolution Dynamics Limb Sounder: Experiment overview, recovery, and validation of initial temperature data, J. Geophys. Res., 113, D16S43, doi:10.1029/2007JD008824.

Resolution:

The vertical resolution is determined from the full-width at half maximum of the averaging kernels. These are shown for each altitude level by the green lines in the left panel of Figure 5.1.1. The blue line in the right panel shows the half-widths explicitly, indicating the vertical resolution is ~1 km from 13-60 km.

The red line in the left panel indicates the fraction of the information that comes from the HIRDLS measurements; values of 1 mean that there is negligible influence from the a priori.

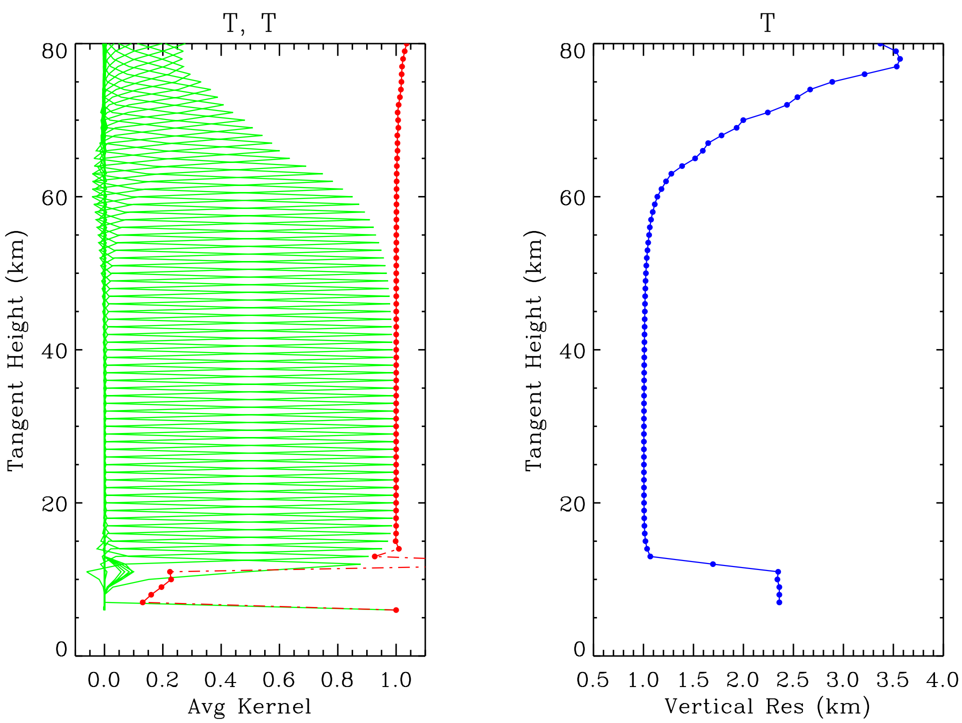


Figure 5.1.1. Averaging kernels (left) and vertical resolution (right) as a function of altitude for HIRDLS temperature profiles.

The averaging kernels were calculated for 15 January at 45°N with a cloud top altitude of 8 km. The rapid drop of the averaging kernel maxima, increase in the half widths, and increase in the fraction of information at altitudes below about 13 km results from relaxation to the a priori. This is the GEOS5 temperature for the day for which the data are retrieved. Thus, the retrieval relaxes seamlessly to temperatures that are accurate in the lower atmosphere. Since the GEOS5 resolution is ~1 km in this altitude range, the resolution of the combined retrieval is not degraded. Under clear conditions HIRDLS profiles do not extend below 383 hPa.

The vertical broadening and reduced peaks of the averaging kernels above 60 km are a result of the reduced signal, and thus reduced signal to noise ratio (S/N), at these levels.

Another indication of the resolution comes from comparison with the results from the radio-occultation temperature profiles obtained by the FORMOSAT-3/COSMIC constellation of 6 GPS receivers launched on 14 April 2006 [Gille et al., 2008; Barnett et al., 2008]. These enable temperatures up to the mid-stratosphere to be retrieved with vertical resolution of about 1 km (C. Rocken, private communication). With 1000-3000 such temperature profiles being measured per day at quasi-random locations, a number of coincidences within 0.75° great circle distance and 500 sec can be found with which to undertake comparisons of the two data types, including the fine vertical structure which tends to vary on a short time scale. In this study, each COSMIC profile was paired with the 1 or 2 HIRDLS profiles that fit the criteria for closeness in space and time. If there were 2, the HIRDLS profiles were averaged together. Where there were COSMIC profiles very close together in space and time, a HIRDLS profile might be used more than once in different comparisons. In addition, the GEOS-5 data were included as an indication of the absence of short vertical scales in the operational meteorological analyses.

For this evaluation, data from 11 July 2006 to 31 October 2007 were used. To isolate the small scales, a parabolic fit was subtracted from all 3 types of profiles over the range 2.2-5.7 scale heights, and the residual profiles then apodized. (The pressure scale height is ln 1013/p, so this corresponds to a range of 112-3.4 hPa. Since the scale height is approximately 7 km, this corresponds to an altitude range of ~24 km).

When the apodized profiles are Fourier transformed, the spectra, plotted as amplitudes vs spatial frequency, are as shown in Figure 5.1.2. Here all 1217 COSMIC profiles are included, irrespective of difference of viewing directions between HIRDLS and COSMIC. As expected, the spectra all have their largest amplitudes at the lowest frequencies. The COSMIC and HIRDLS spectra are very similar for frequencies up to 12 cycles per 24 km, or a 2 km wavelength, and beyond, although the amplitudes become quite small. Clearly these small-scale motions are not contained in the GEOS-5 analyses.

This establishes that HIRDLS is capable of resolving vertical variations in the atmosphere with scales down to ~2 km wavelengths, or 1 km features.

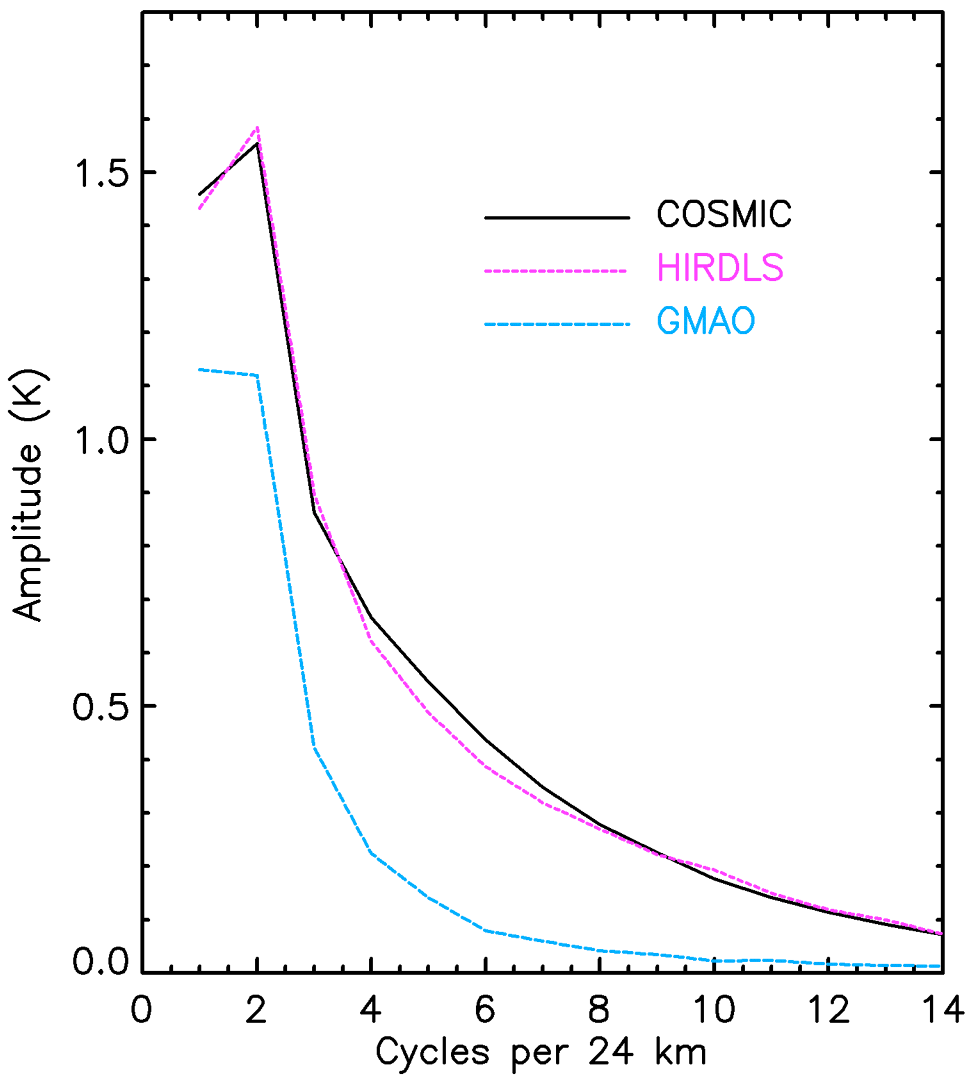


Figure 5.1.2. Comparison of amplitudes versus small scale wavelengths among HIRDLS, COSMIC and GEOS-5. HIRDLS and COSMIC recover vertical scales down to and beyond 12 cycles per 24 km, or 2 km wavelengths.

This is consistent with the results obtained by Wright et al., [2011].

Precision

The precision of the temperature data was calculated as described in Section 5.0. The results are displayed in Figure 5.1.3. At pressures > 400 hPa the retrieval precision is that of the GEOS-5 data that are essentially those of the a priori data there. For pressures < 100 hPa the precision is that of the retrievals, with negligible influence from the a priori. As noted above, the method of estimating the precision may necessarily include some atmospheric variability, so is an upper limit to HIRDLS retrieval precision. This may contribute to some of the increase with altitude where the effect of small-scale wave motions, especially gravity waves, may be included.

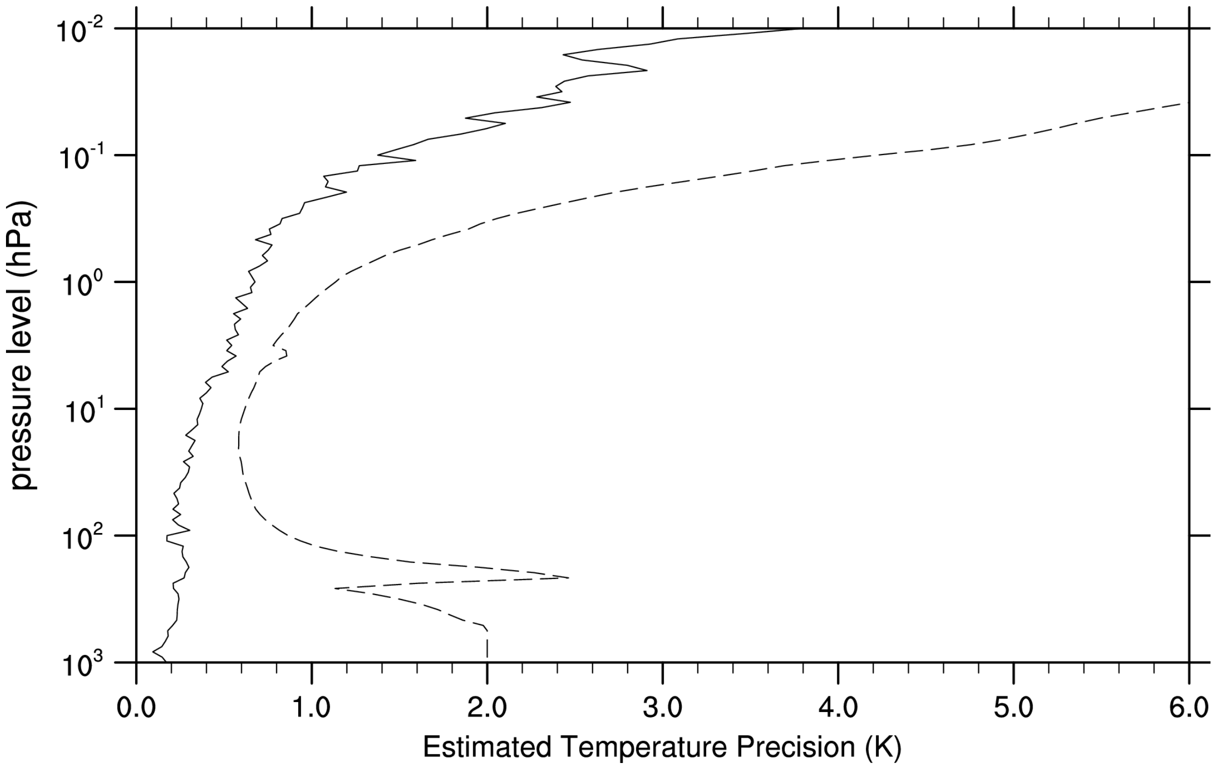


Figure 5.1.3. Estimated precision of HIRDLS V6 Temperature retrievals (solid line), compared with precision predicted by the retrieval algorithm (dashed line).

Certainly above 0.1 hPa reduced S/N plays a major role, and relaxation to the a priori keeps the precision from being even larger.

The random error predicted by the retrieval algorithm may be overestimated because we believe the uncertainty of the forward radiative transfer model may be less than the values we have used.

Accuracy (Biases)

HIRDLS temperatures have been compared to several data sets in an effort to determine the extent and magnitude of any biases. The results shown here update results of comparisons described by Gille et al., [2008] for V3. An important set of profile comparisons up to about 30 km is between radiosondes and nearby HIRDLS temperatures. Figure 5.1.4 shows comparisons between high-resolution radiosonde profiles and 2 nearby HIRDLS retrievals at St. Helena and Gibraltar. The differences in space and time are given. Points to note, in addition to the good agreement, are the way the HIRDLS retrievals follow the small-scale vertical structure in the radiosonde data, as discussed above. Note in particular that one of the Gilbraltar retrievals follows the sharp kink at the lower tropopause exactly, and both follow the double tropopause structure.

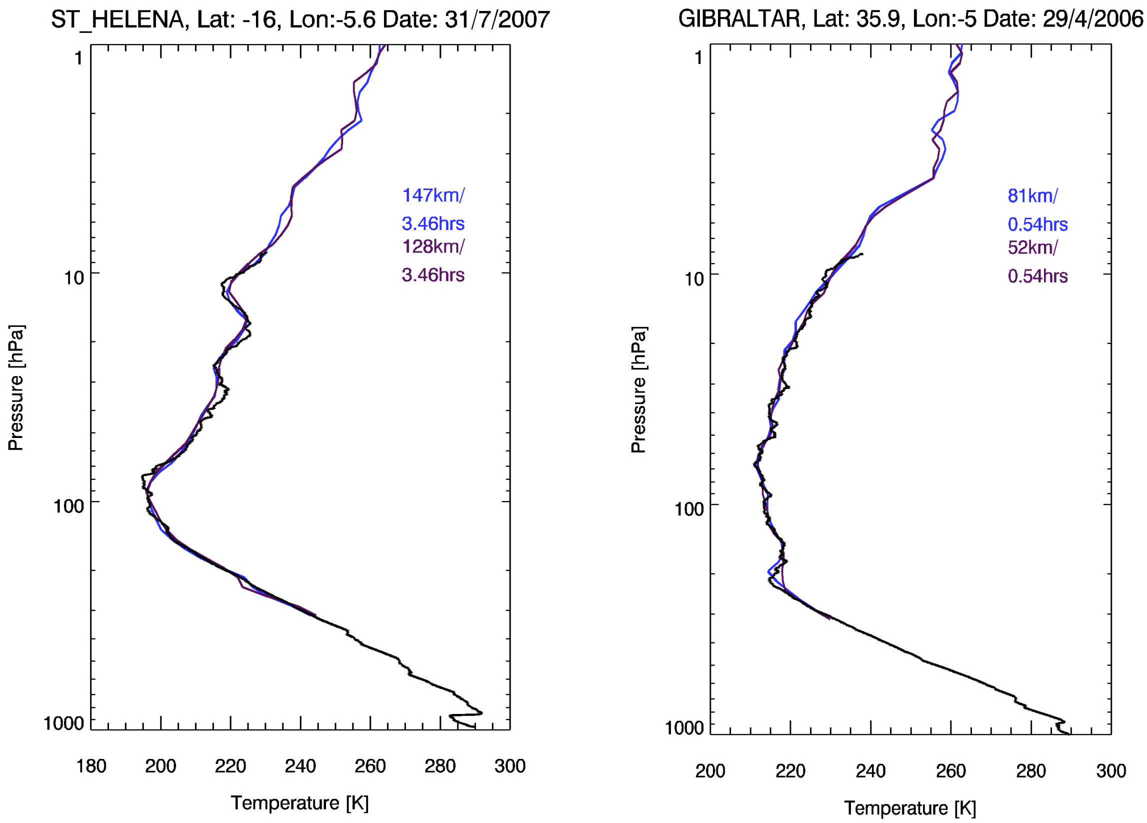


Figure 5.1.4. Temperature comparisons between radiosonde profiles at St. Helena (left) and Gibraltar. Black lines are high-resolution radiosondes, blue and magenta are two nearby HIRDLS retrievals. Differences in distances and times are given.

Statistics of such comparisons at Gibraltar, a representative site, are shown in Figure 5.1.5. The green line indicates that HIRDLS is within 0.5K of the sondes from ~ 300hPa to 15 hPa. The blue dotted lines are the standard deviation (s.d.) of the differences of HIRDLS minus sondes, while the red dotted lines are ± the precision value calculated in the retrieval code. Inclusion of the stated precision of the radiosondes does not explain the differences. It is believed that most of the difference comes from differences in time and space between the radiosondes and the HIRDLS profiles, as well as possible effects of gradients along the HIRDLS line of sight which are not completely corrected. Differences in vertical resolution may also enter, although HIRDLS is sensitive to temperature variations with wavelengths as small as 2 km as pointed out above and in Gille et al., [2008].

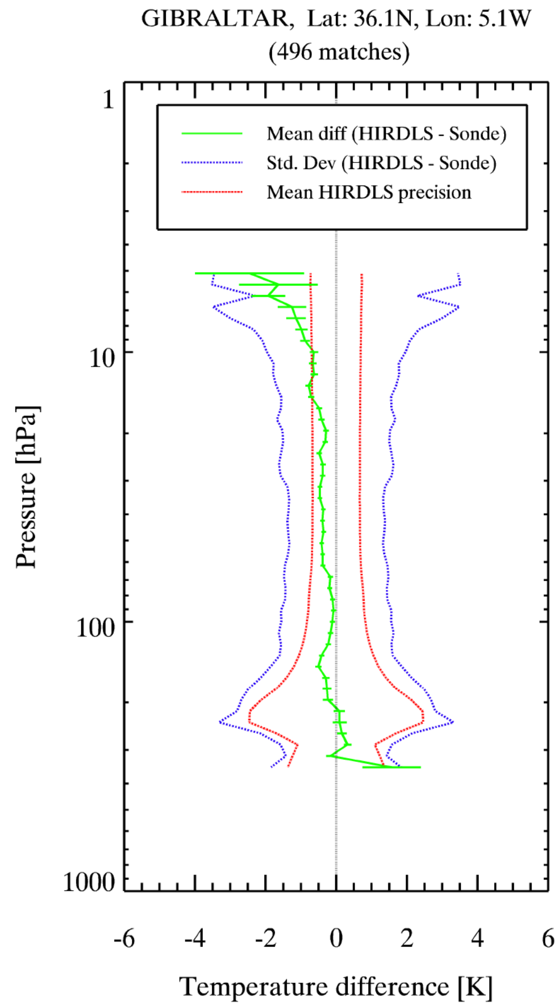


Figure 5.1.5. Statistics of HIRDLS minus sonde differences for Gibraltar. Green line shows mean differences, blue dots show ± 1 standard deviation of the differences, while red dots show ± 1 standard deviation predicted by the retrieval algorithm.

Comparisons with lidar data allow extending the assessment into the mesosphere. An example of such a comparison with the lidar at Mauna Loa is shown in Figure 5.1.6. This again shows the retrieval following the sharp tropopause and stratopause, and tracking the temperature up to 0.01 hPa (~80 km).

Statistics for comparisons between HIRDLS temperatures and the lidar for Table Mountain, California, are shown in Figure 5.1.7. HIRDLS temperatures are within 2K of the lidar temperatures up to 1 hPa, then remain ~ 5K cooler up to 0.01 hPa. Similar statistics are obtained at Mauna Loa.

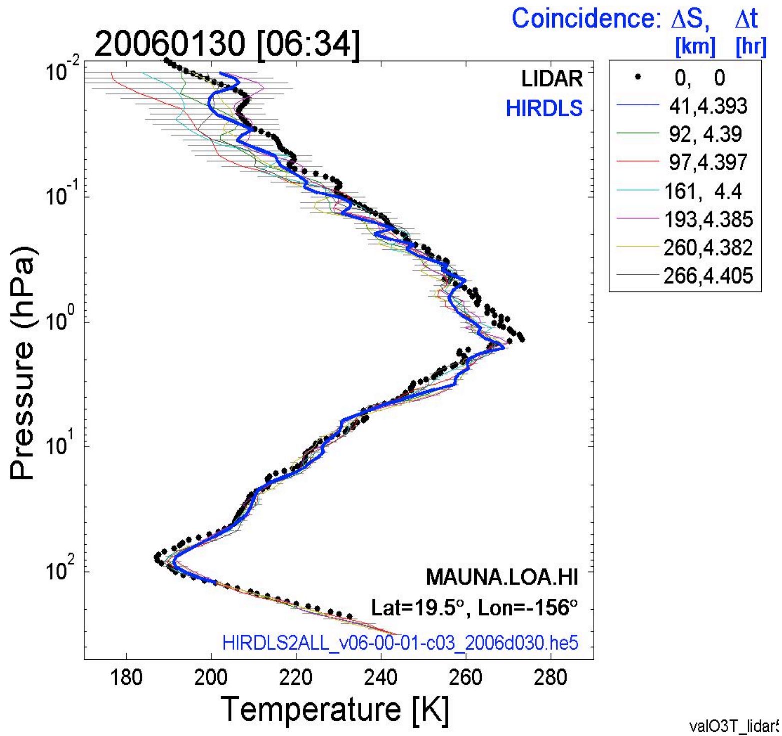


Figure 5.1.6. Comparison between lidar temperature measurement at Manua Loa, Hawaii on 30 January 2006 (black dots) with the closest HIRDLS retrieval, where the closest (41 km distant, 4.4 hours different in time) (solid blue line) and 6 other nearby retrievals (thin lines.)

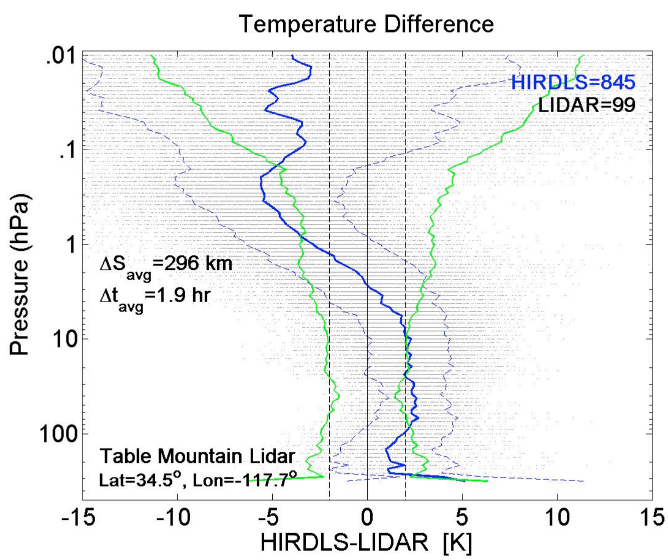


Figure 5.1.7. Statistics of HIRDLS minus lidar temperatures for 99 lidar profiles and 845 closely coincident HIRDLS retrievals. The vertical dashed lines indicate ± 2K, the horizontal lines indicate the standard deviation of the differences, and the green lines indicate the random error predicted by the retrieval algorithm.

To investigate possible latitudinal or seasonal biases, comparisons are next shown with global data such as those obtained from other validated satellite instruments or operational assimilated data sets. A set of such comparisons is presented in Figure 5.1.8, which compares latitude-altitude cross-sections of HIRDLS minus other data differences for November 2007.

Comparison with data from the Sounding the Atmosphere by Broadband Emission Radiometry (SABER) evaluated by Remsberg et al., [2008] shown in the top panel does not indicate large latitudinal variations, except possible at high southern latitudes. This supports a small warm region at the tropical tropopause, but indicates cooler temperatures in the stratosphere, good agreement around the stratopause, and cooler temperatures by a few degrees in the mesosphere.

A comparison between HIRDLS and the European Centre for Medium-range Weather Forecasting (ECMWF) ERA-Interim assimilated data [Dee et al., 2011] over the HIRDLS latitude range for November 2007 is shown in the middle panel of Figure 5.1.8. From this we see that HIRDLS V6 temperatures are within 1K of ECMWF temperatures from 400 to ~3 hPa, becoming lower above that level. Again, there is little latitudinal structure, but again an indication that HIRDLS may be warm at the tropical tropopause. (The ERA-Interim data for this study are from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds627.0.)

Finally, the lower panel shows HIRDLS minus Microwave Limb Sounder (MLS) version 3.3 temperatures, indicating agreement within 1-2 degrees in the stratosphere, but with HIRDLS cooler in the upper mesosphere. The earlier V2.2 has been validated by Schwartz et. al., [2008], while the Data User's Guide for V3.3 may be found at http://mls.jpl.nasa.gov/data/datadocs.php There is no indication of latitudinal variation, but there is a small scale vertical banding not apparent in the other comparisons.

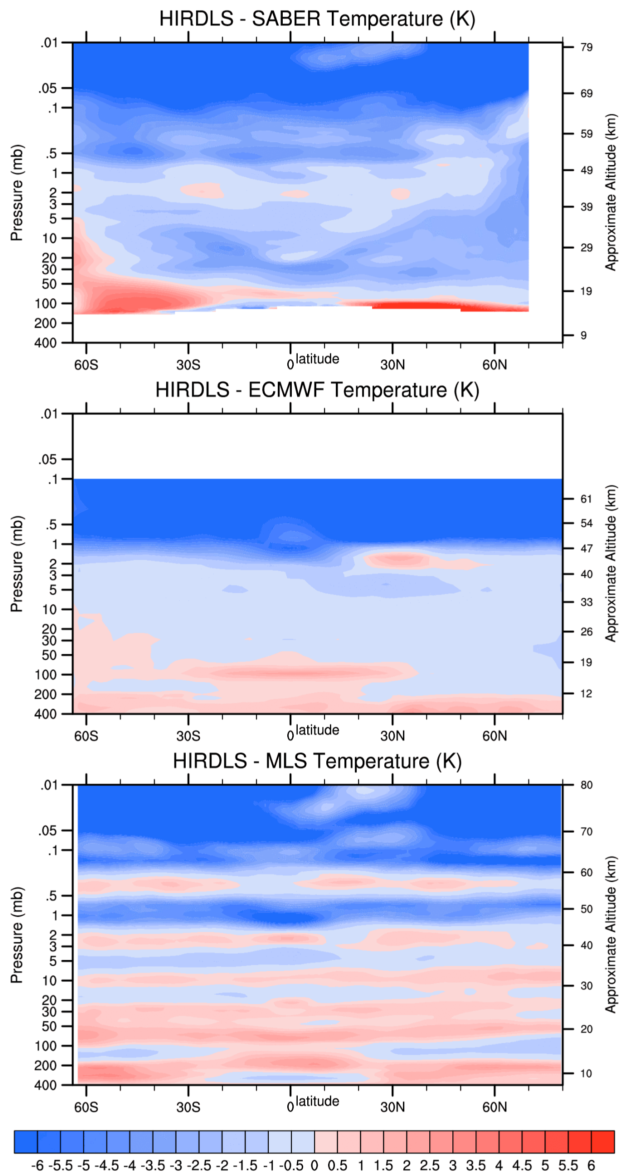


Figure 5.1.8. Monthly mean difference cross-sections, HIRDLS minus SABER (top panel), HIRDLS minus ECMWF ERA-Interim (center panel) and HIRDLS minus MLS (bottom panel).

Summary

The HIRDLS temperatures have 1 km vertical resolution, a precision between ≤ 0.5K (lower stratosphere) to > 3K (mesopause) and are accurate to ≤ 1K from the 300-400 hPa to 1 hPa, becoming cooler above that level. In the mesosphere HIRDLS temperatures are cooler than lidar temperatures and other global data from SABER, MLS, and ECMWF ERA-Interim, but they show the same temporal and spatial variations seen in other observations.

5.2 Ozone (O3)

Species: O_3 (ozone)
Data Field Name: 03
Useful Range: 422 hPa - 0.1hPa
Vertical Resolution: 1 km
Contact: Bruno Nardi
Email: nardi@ucar.edu
Validation Paper: Nardi, B., et al., [2008], Initial validation of ozone measurements from the High Resolution Dynamics Limb Sounder, *J. Geophys. Res.*, 113, D16S36, doi:10.1029/2007JD008837.

Vertical Resolution

The averaging kernels shown in Figure 5.2.1 give the vertical resolution most directly. The resolution is 1km between 12-62 km, roughly 200-0.2 hPa. The resolution decreases to about 2 km at 10 km (~260 hPa) and earthward, and at 62 km (0.2 hPa) and spaceward.

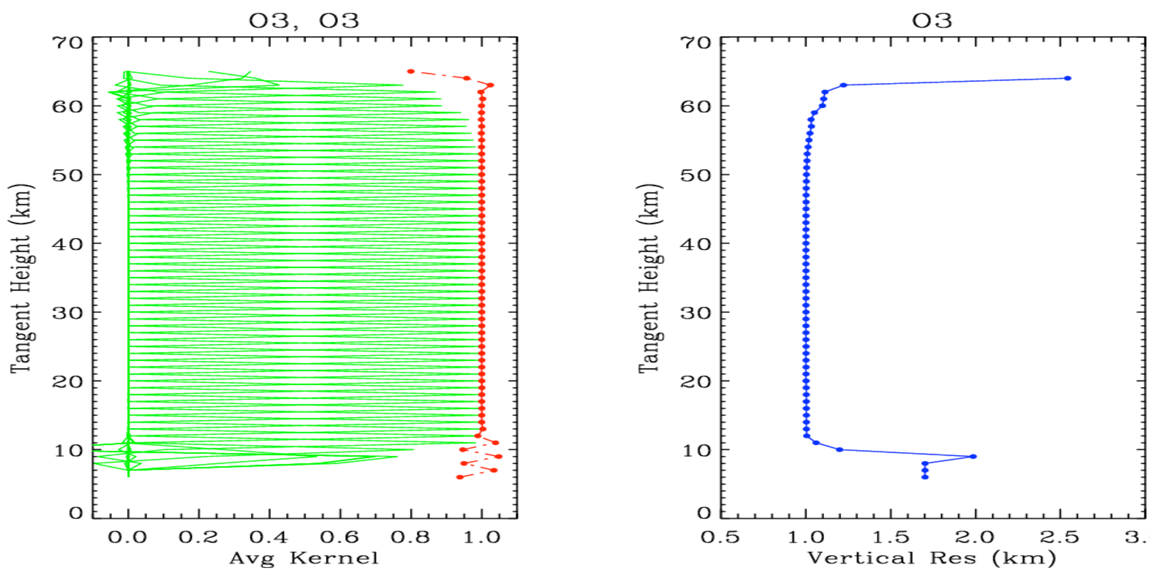


Figure 5.2.1. Shown are the averaging kernels for HIRDLS ozone (left), and the ozone vertical resolution (right) as a function of altitude.

Comparisons of HIRDLS ozone with ozonesondes profiles taken during the NH mid- and high latitude winter and spring, where ozone lamina are widespread in the upper troposphere lower stratosphere (UTLS) region, show clearly that HIRDLS resolves the fine vertical scales of these features (see Figure 5.2.2). This is confirmed statistically by calculating the altitude-dependent HIRDLS-sonde ozone bias for all comparison cases, and comparing it with the bias using only those cases where strong lamina were present. If the presence of thin ozone lamina with high vertical gradients posed a greater difficulty for HIRDLS to resolve, then either the mean difference (bias), or the standard deviation of the differences would have larger values for the lamina-only case in the region of the profile where those lamina are present; and this is not the case as seen in Figure 5.2.3. In fact, the bias is somewhat smaller for the lamina-only case, near ~150 hPa, so it can be inferred that the ozone lamina are resolved with similar accuracy compared to the more gradually varying ozone profiles.

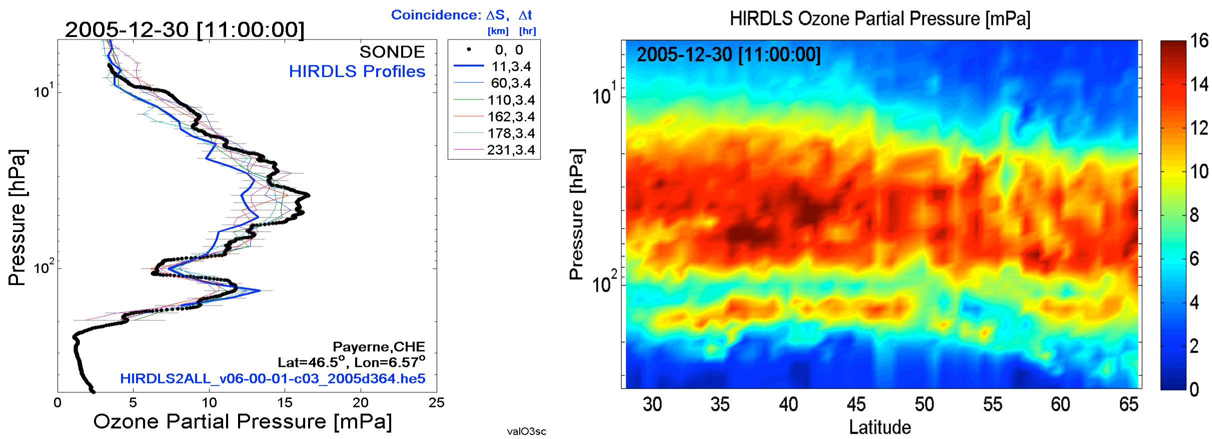


Figure 5.2.2. Shown is a double layered ozone filament in the NH spring UTLS, extending down to 300 hPa (left). The comparison between an ozonesonde and the closest six coincident HIRDLS profiles (10-230 km, 3 hours), indicates that the vertical features are measured by HIRDLS.

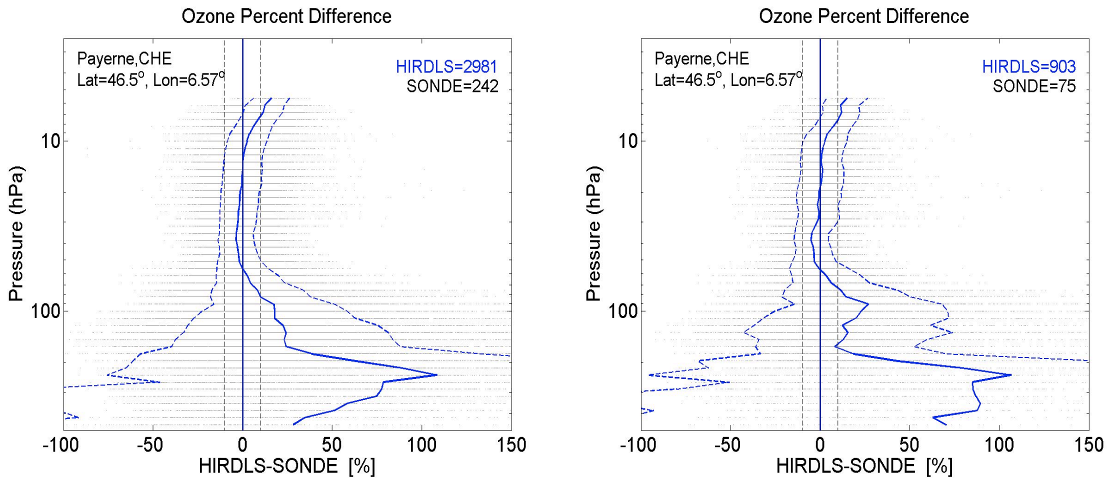


Figure 5.2.3. Above are plots of the HIRDLS ozone bias, in percent-difference units, with respect to ozonesonde profiles for the WOUDC site at Payerne, Switzerland (46.5N). The plot on the left hand side includes all coincident profiles from years 2005, 2006 and 2007. The plot on the right includes only the coincident profiles in which strong lamina were present. Numbers of profiles used are inset on the upper RHS of each plot. The fact that neither the mean difference nor the standard deviation of the differences is significantly higher for the lamina-only case (right) is indicates that HIRDLS is measuring the thin lamina with close to the same accuracy as profiles with less vertical structure.

Precision

Figure 5.2.4 shows observed precision estimates (blue lines) for latitude bands centered at 70°N, 10°N and 50°S, respectively, compared with predicted ozone precision values (red lines, O3Precision parameter in HIRDLS2 data files). The method used to determine the observed precision is described in Section 5.0, and agrees very well with the predicted precision.

Observed ozone precision in mixing ratio units is typically 100-300 ppbv or less; it is about 10-100 ppbv in the tropical UTLS. In percentage units, the precision is 2-5% in the region earthward of 0.5 hPa and spaceward of 50-100 hPa depending on latitude (higher pressure corresponding to the higher latitudes). At the top of the profiles, between 0.5-0.1 hPa, ozone precision increases spaceward from 5% to 25% for all latitudes. Precision between 100-260 hPa is between 5% and 30%, increasing earthward, at mid- and high latitudes. In the tropics there is a bias, which peaks at 100% or more in the region centered near 70-100 hPa. It is believed that this is due to the presence of aerosols, and a correction is currently being developed.

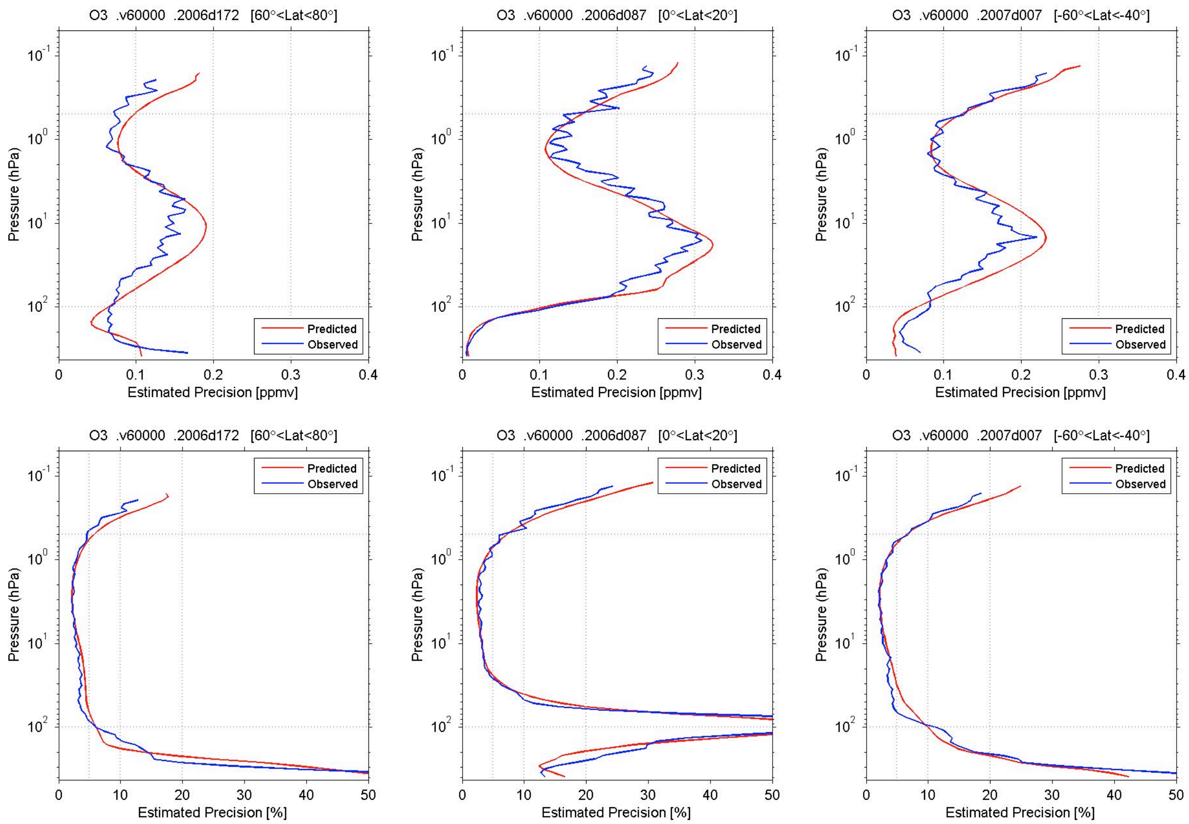


Figure 5.2.4. Shown are the predicted (red) and observed (blue) ozone precision, in units of volume mixing ratio (top row) and percent (bottom row). The 'predicted' precision is computed by the retrieval algorithm, and averaged over the indicated latitude band. The "observed" precision is computed as the average of ten rms differences from detrended sequences of 12 consecutive profiles (see Section 5). Three representative latitude bands are shown for undisturbed periods (i.e., summer in the extra-tropics): 60-80°N (left), 0-20°N (center), 60-40°S(right).

Accuracy

The bias, in terms of mixing ratio and percentage, are determined primarily from comparisons with ozonesondes, ozone lidars, Atmospheric Chemistry Experiment – Fourier Transform Spectrometer (ACE-FTS) and Aura-MLS.

High Latitudes. Comparisons with coincident ozonesonde measurements northward of 60 degrees latitude indicate that HIRDLS V6 ozone has a low bias of about 100-400 ppbv, approximately 1-10%, between 10-70 hPa. Earthward of 70 hPa the bias typically changes sign, from negative to positive, with increasing pressure to typical values of 0-100 ppbv at 200hPa, and may correspond to a rapid increase from 10-100+% at 200 hPa and below. See for example, Figure 5.2.5, top row. The known ozonesonde measurement inaccuracies of up to 10% and greater above 10 hPa precludes their use for determining HIRLDS accuracy in this region.

These biases are in general agreement with comparisons with Aura-MLS (Figures 5.2.7 and 5.2.8) and the satellite-borne ACE-FTS (Figure 5.2.9, top row), in the region earthward of 10 hPa. Comparison with ACE-FTS and MLS also indicate the HIRDLS high bias increases from -10% at 10 hPa, to about +10% at 0.5 hPa (roughly 250ppbv), and a generally positive bias approaching about 100-300 ppbv (50%) at the top of the profile (0.1 hPa). Biases are similar in both hemispheres.

Mid Latitudes.. At mid-latitudes poleward of 40 degrees there is a bias of less than ±200 ppbv, 5% or less, between 1-100 hPa. Between 100-400 hPa the bias is positive with a magnitude <100ppbv, resulting in a maximum high bias of 20-100% at about 100-200 hPa. See Figure 5.2.5, middle row. Comparisons with the ground-based lidar at Table Mountain Facility (39°N) indicate agreement of 3% or better (<300 ppbv) between 2-50 hPa (Figure 5.2.6, top).

Low Latitudes. The bias between 1-30 hPa is within ±10% of all correlative measurements compared here, and is often within ±5% as indicated by the comparison with the Mauna Loa lidar (Figure 5.2.6, bottom). The bias is generally negative in a sub-region centered near 10 hPa, and is typically positive elsewhere. Between 30-150 hPa there is a high bias of 100-500 ppbv with the peak centered near 70 hPa. This results in a 10-50% high bias above 50 hPa, increasing downward, and a 50-100+% high bias that peaks at about 100 hPa. Between 150-400 hPa the bias is <100ppbv, often 10's of ppbv, but due to the low ozone amounts here it results in a ±50% bias. See Figure 5.2.5, bottom row; Figure 5.2.7; Figure 5.2.9, third row.

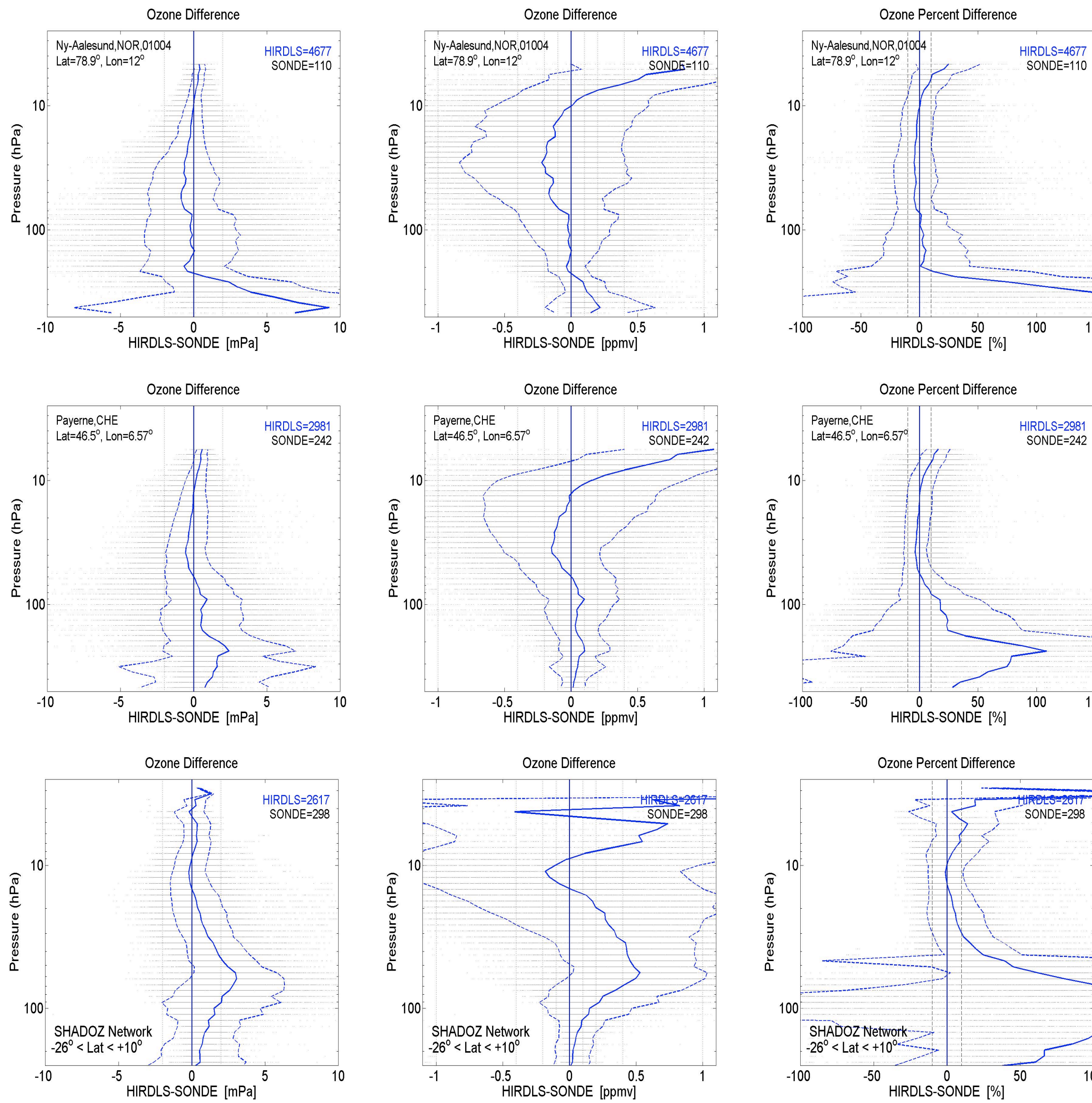


Figure 5.2.5. The mean ozone difference (solid blue lines) from comparisons with ozonesondes are shown for the high latitude station at Ny-Alesund (top), for the mid-latitude station at Wallops Island (middle) and for the low latitude SHADOZ Network, 26 °S < Lat < 10°N (bottom). From left to right the plots are in ozone units of partial pressure (mPa), volume mixing ratio (ppmv) and percentage difference. The dashed blue lines are the standard deviation of differences.

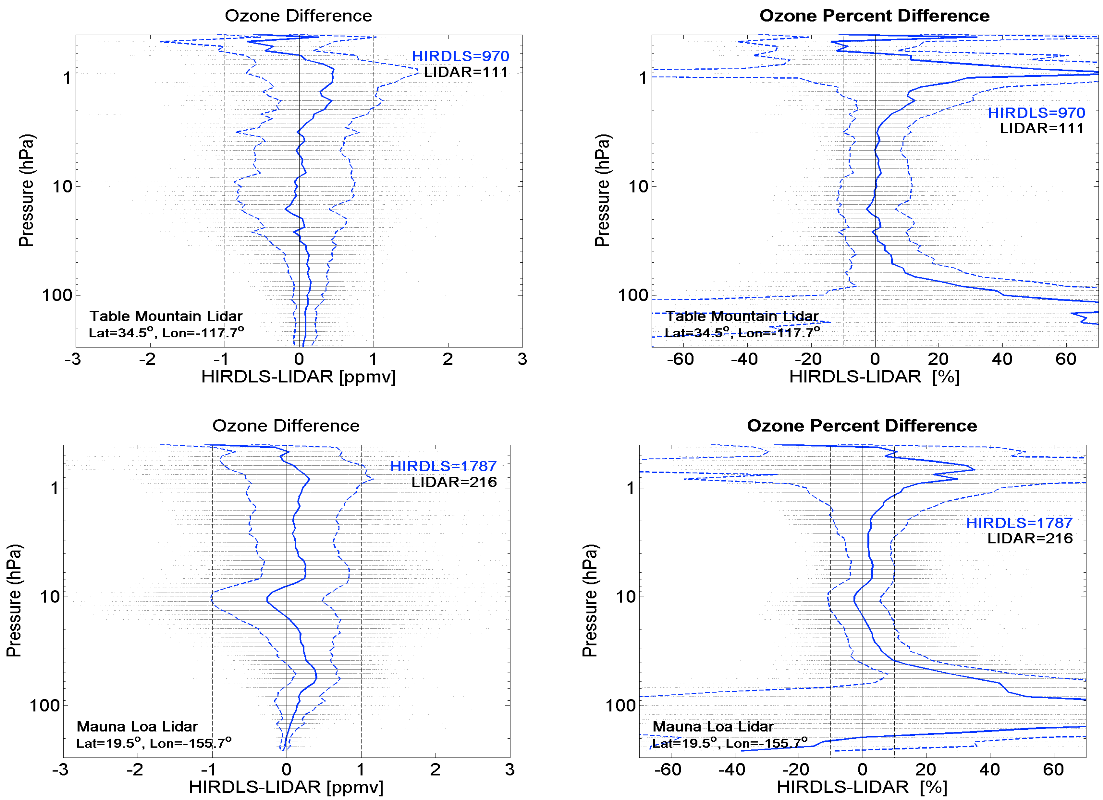


Figure 5.2.6. The mean ozone difference (solid blue lines) from comparisons with lidars is shown for the mid-latitude station at Table Mountain Facility (39°N, top row) and for the low latitude Mauna Loa Observatory (20°N, bottom row). Left plots are in ozone units of volume mixing ratio (ppmv); right side plots are percentage difference. The dashed blue lines are the standard deviation of differences.

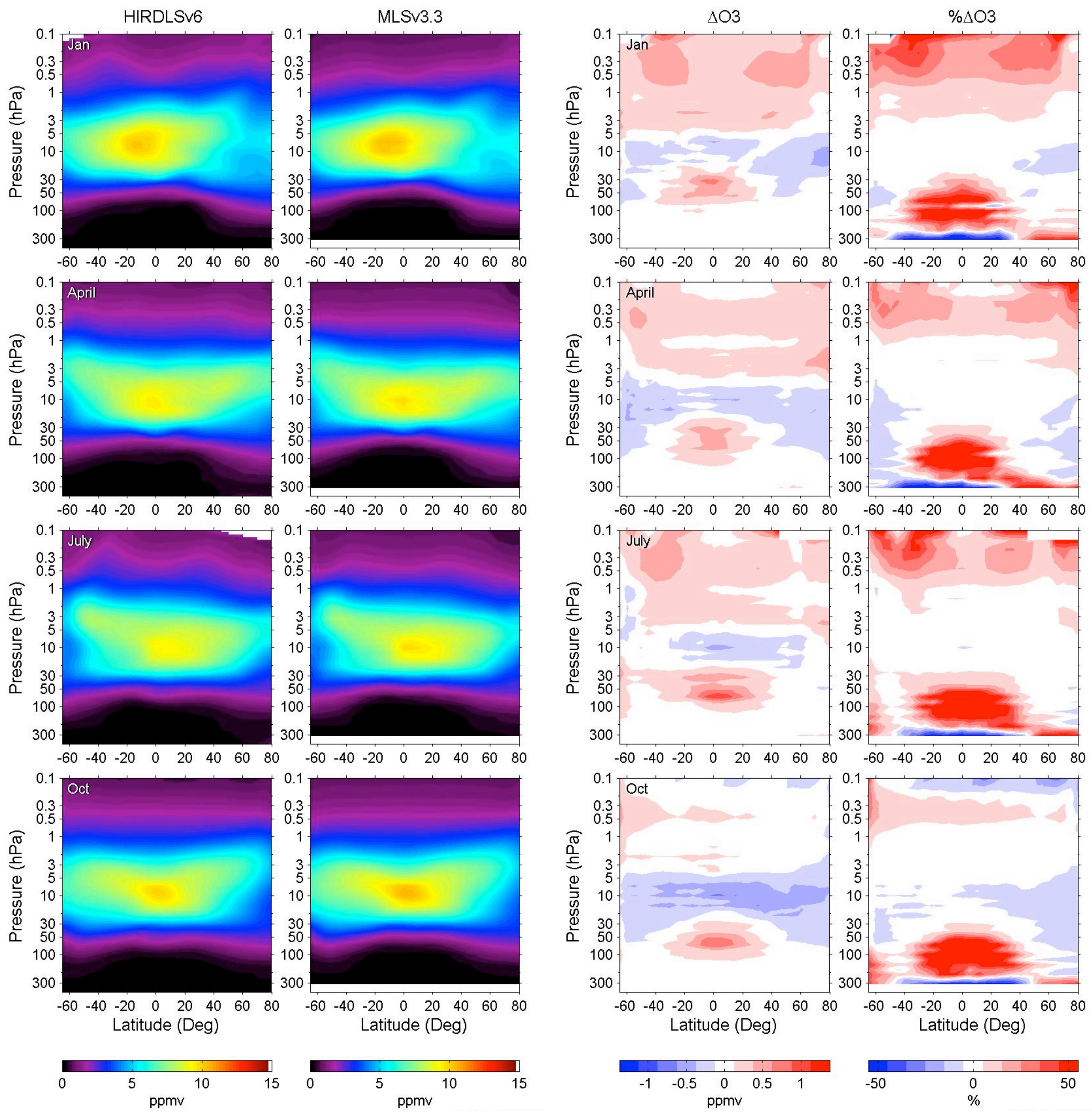


Figure 5.2.7. The two left columns show the monthly zonal mean cross sections for HIRDLS and MLS ozone (ppmv), for the months: January, April, July and October of 2006 (as indicated at top left, inset, of each row). The mixing ratio difference and percentage difference (HIRDLS–MLS)/(MLS) are shown in the 3rd and last columns respectively. The white areas in the difference and percent difference plots correspond to 0 ppbv ±125 ppbv and 0%±5%, respectively; each blue and red color increment in the color band corresponds to a multiple of 250 ppbv and 10%, respectively.

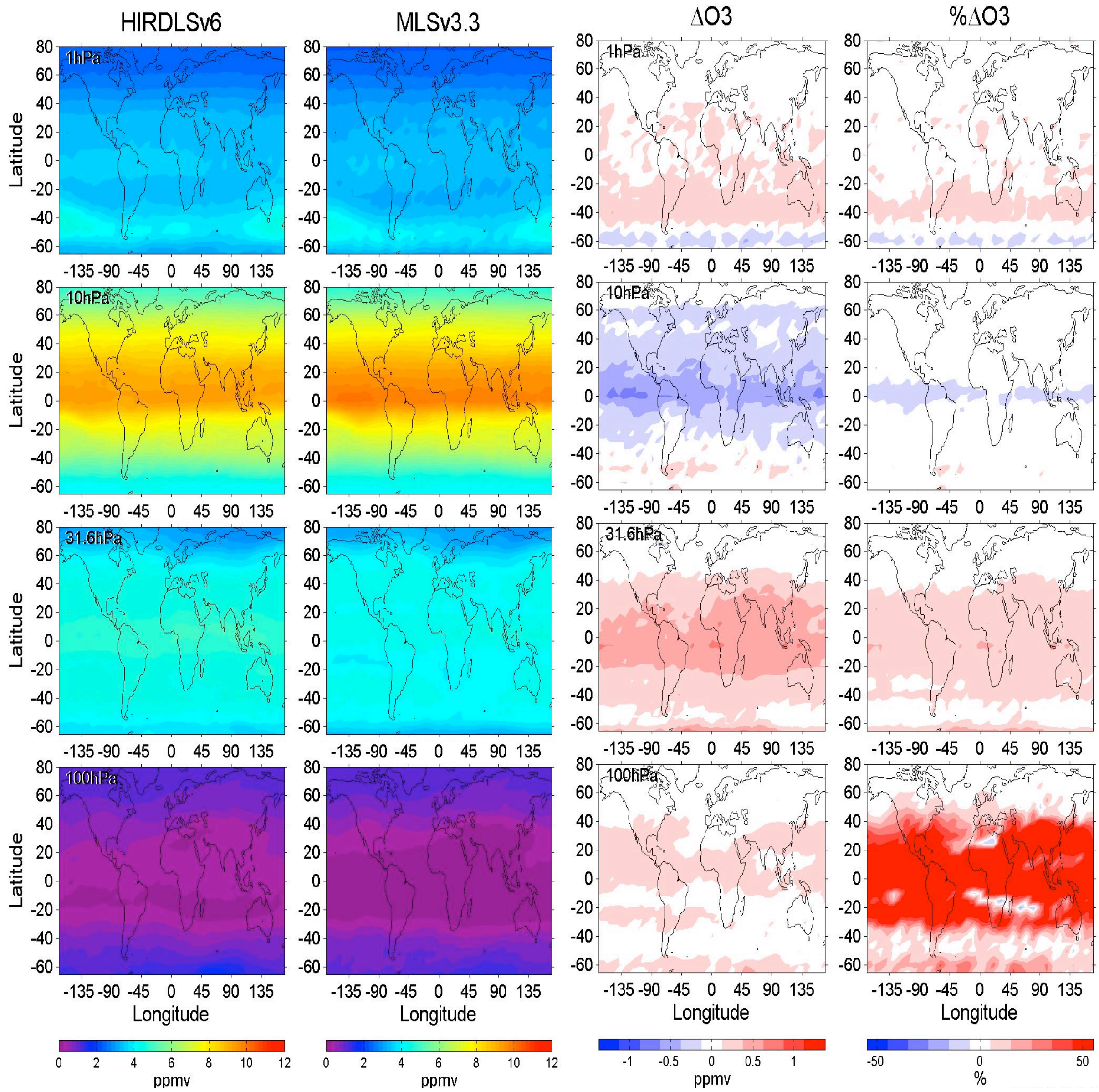


Figure 5.2.8. Shown are the longitude-latitude cross sections of HIRDLS and MLS ozone (ppbv) for July 2006. The rows depict the average for the approximate pressure levels: 1 hPa, 10 hPa, 31 hPa and 100hPa, from top to bottom. The mixing ratio difference and percentage difference (HIRDLS–MLS)/(MLS) are shown in the 3rd and last columns respectively. The white areas in the difference and percent difference plots correspond to 0 ppbv ±125 ppbv and 0%±5%, respectively; each blue and red color increment corresponds to a multiple of 250 ppbv and 10%, respectively.

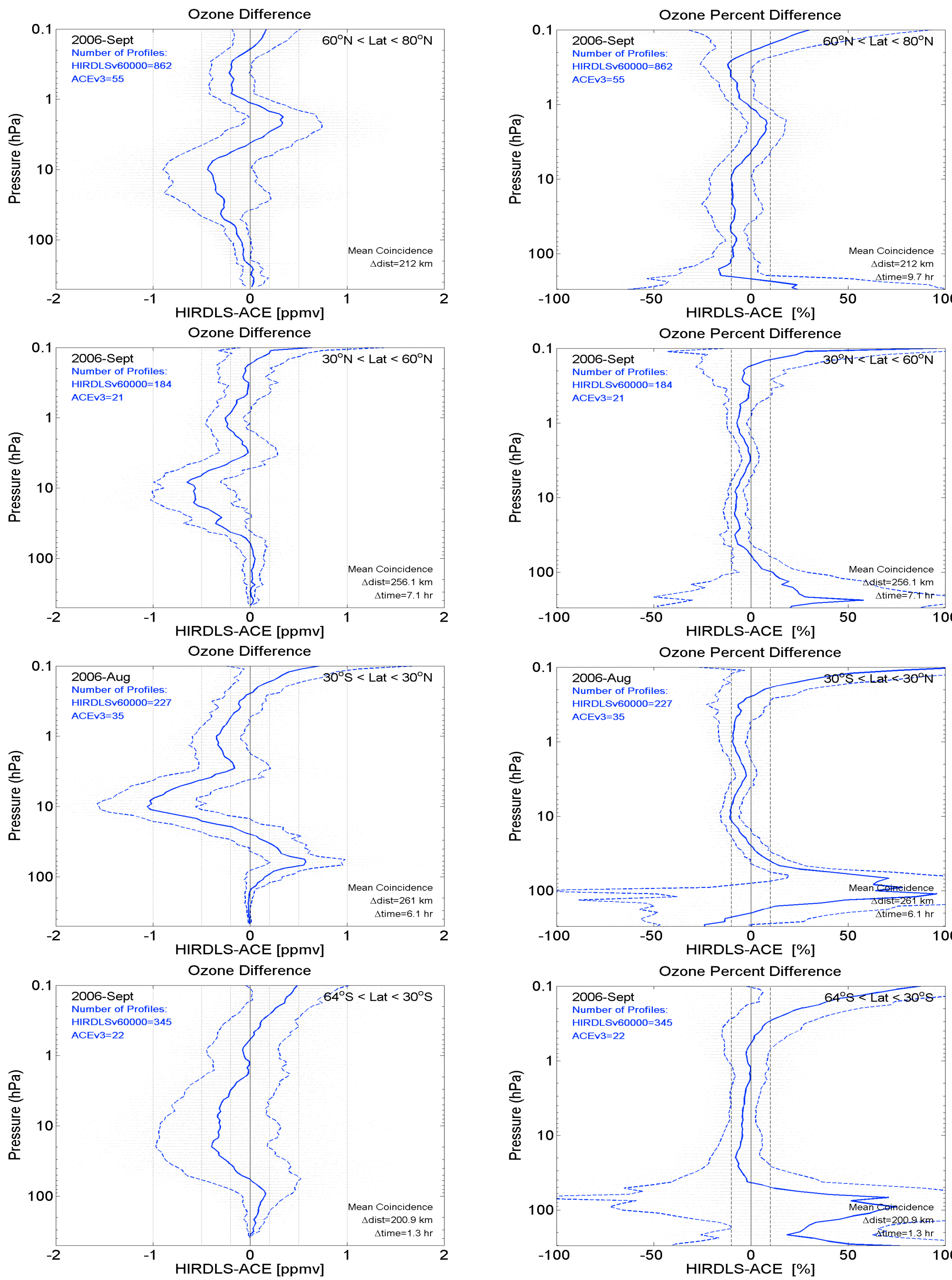


Figure 5.2.9. Shown are mean Ozone differences (solid blue lines) from comparisons with ACE-FTS v3 measurements. Results for coincidences during the month of September 2006 are shown for high latitudes (60-80N, top), for the mid-northern latitudes (30-60N, 2nd row) and for the mid-southern latitudes (30-64S, bottom). Results for coincidences during the month of August 2006 are shown for low latitudes (30S-30N, 3rd row). The plots are in units of volume mixing ratio (left) and percentage difference (right). The dashed blue lines are the standard deviation of differences.

Data Screening and Artifacts

Negative values of the predicted error ('O3Precision') signify that a large proportion of the ozone information comes from the a priori. For example, at pressure levels earthward of a non-zero CloudTopPressure there is a strong a priori influence in the retrieved ozone. The ozone useful range is specified to 422 hPa, however the percentage of profiles that extend down to that pressure maintaining a positive precision are about 20%; about 50% of the profiles reach 261 hPa (see Figure 5.2.10).

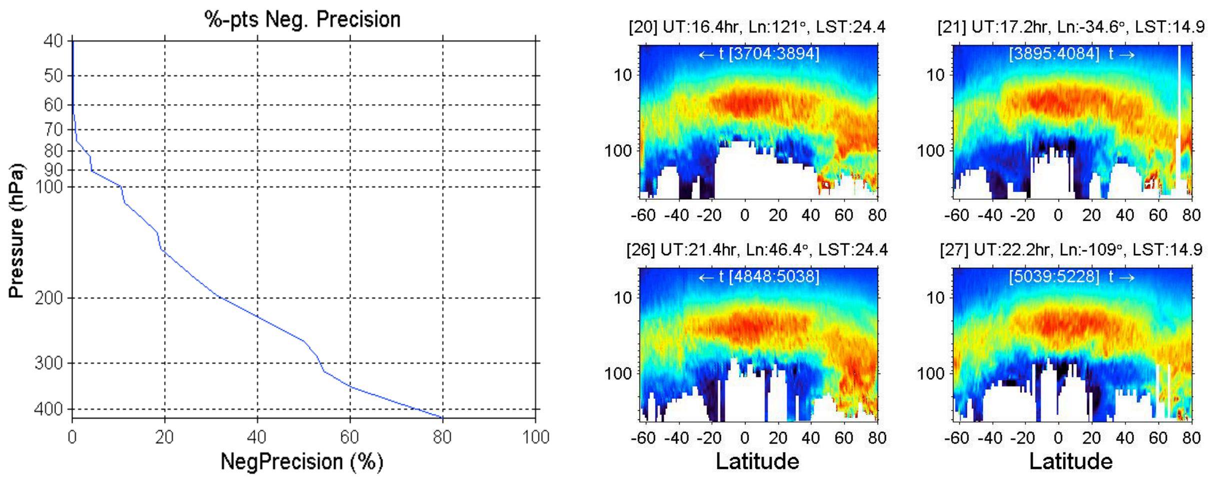


Figure 5.2.10. On the left is a typical vertical distribution of negative precision values (high a priori influence) for the earthward portion of profiles over a 24-hour period. On the right are ozone partial pressure curtain plots for two of the orbits on this day, separated into descending and ascending nodes (left and right respectively), with negative-precision data points eliminated (white areas).

There is a small daytime/nighttime ozone asymmetry, where daytime values are slightly higher than nighttime values by about 5-10%, that is an artifact of unknown cause. It is a small effect, and is not obviously evident from comparing descending and ascending nodes side-by side.

Profiles in the tropics exhibit a high bias approaching 100% or more centered near 100 hPa, corresponding to roughly 50-200 ppbv (and up to 500ppbv at 70 hPa, 50% due to the higher ozone concentration there). This is believed to be an issue related to the presence of aerosols and is currently under investigation.

It is not expected that ozone spikes linked to the presence of undetected clouds, a problem cited in earlier HIRDLS releases, contribute significantly to this high bias, but isolated instances of such spikes with unrealistically high ozone values may still be possible. In such cases one may apply a “gradient filter” by removing points at, and earthward of, the level where the ozone vertical-gradient threshold of >1.9 ppmv/p-level is reached. This filter should be used only in the tropics and not in winter and spring at mid- and high latitudes (especially between Dec-May, roughly 30°N-60°N), where thin ozone lamina with high vertical gradients are known to be prevalent between 50-200 hPa (see Figure 5.2.2).

Summary

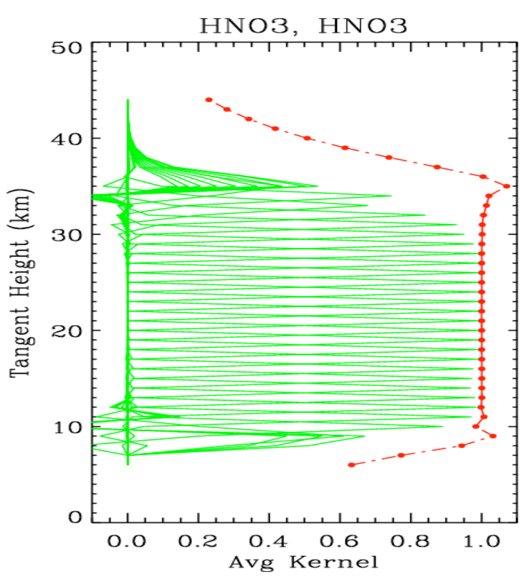
HIRDLS ozone has a 1 km vertical resolution, with a precision of 3-5%. Most of the data are biased within 10% of other data sources, often within 5% or less. There is a high bias in the tropical UTLS region, probably due the presence of aerosols there. There exists a small day-night asymmetry in the ozone magnitude, with higher values in daytime (ascending orbital node). About 20% of the profiles extend down to 400 hPa and about 50% extend to 250 hPa maintaining positive precision; comparisons with ozonesondes indicate that these are useful, however they should be used with caution.

5.3 Nitric Acid (HNO3)

Species:	Nitric Acid (HNO_3)
Data Field Name:	HNO_3
Useful Range:	215 hPa – 7.5 hPa
Vertical Resolution:	~ 1 km
Contact:	Bruno Nardi
Email:	nardi@ucar.edu
Validation Paper	Kinnison, D. E., et al., [2008] Global observations of HNO_3 from the High Resolution Dynamics Limb Sounder (HIRDLS), *J. Geophys. Res.*, 113, D16S44, doi:10.1029/2007JD008814

Precision

The predicted precision is derived by the HIRDLS level-2 retrieval algorithm. The observed precision is obtained by examining HIRDLS variations between adjacent scans in regions in which there is small natural variability. Predicted and observed precision are shown in Figure 5.3.2. The HIRDLS HNO_3 at pressures <10 hPa (altitudes >32 km) is characterized by large uncertainties (≥0.5ppbv and ≥50%) and should be used with caution. At pressures 10 hPa – 215 hPa the observed precision is between 0.1 – 1.0 ppbv, increasing spaceward, typically slightly less than the predicted precision. Because the HNO_3 mixing ratio can vary significantly with latitude and altitude, the percentage error in HNO_3 will also vary, with the lowest values of ~5% (in high latitudes), but can be much larger if the HNO_3 abundance is low.



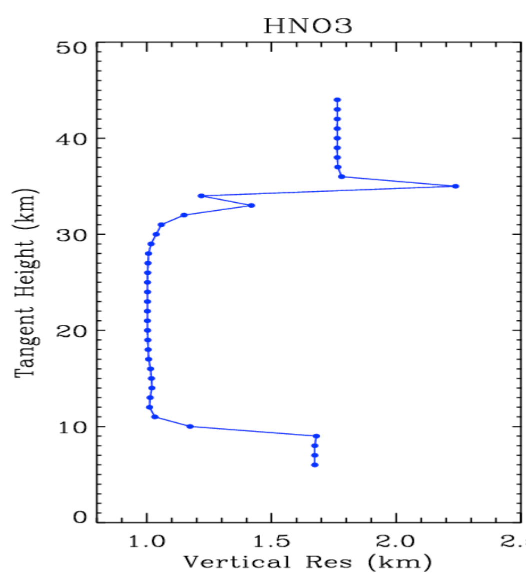


Figure 5.3.1: HIRDLS HNO_3 averaging kernels and full width half maximum (FWHM) vertical resolution profiles. The left plot shows the averaging kernels (green lines) and the integrated area under each kernel (red line). Where values of unity indicate that all of the information for that

vertical region is coming from the measurements and not the a priori estimate. The right plot represents the vertical resolution as derived from the FWHM of each kernel.

Vertical Resolution

The HIRDLS HNO_3 vertical resolution is approximately 1 km, but does vary with altitude and latitude, as shown in Figure 5.3.1. Because of the low HNO_3 mixing ratios in the upper tropical atmosphere, the resolution degrades above 35 km altitude, although, because the red line remains near 1, the information is still coming from the measurements, with only minimum contributions from the a priori estimates.

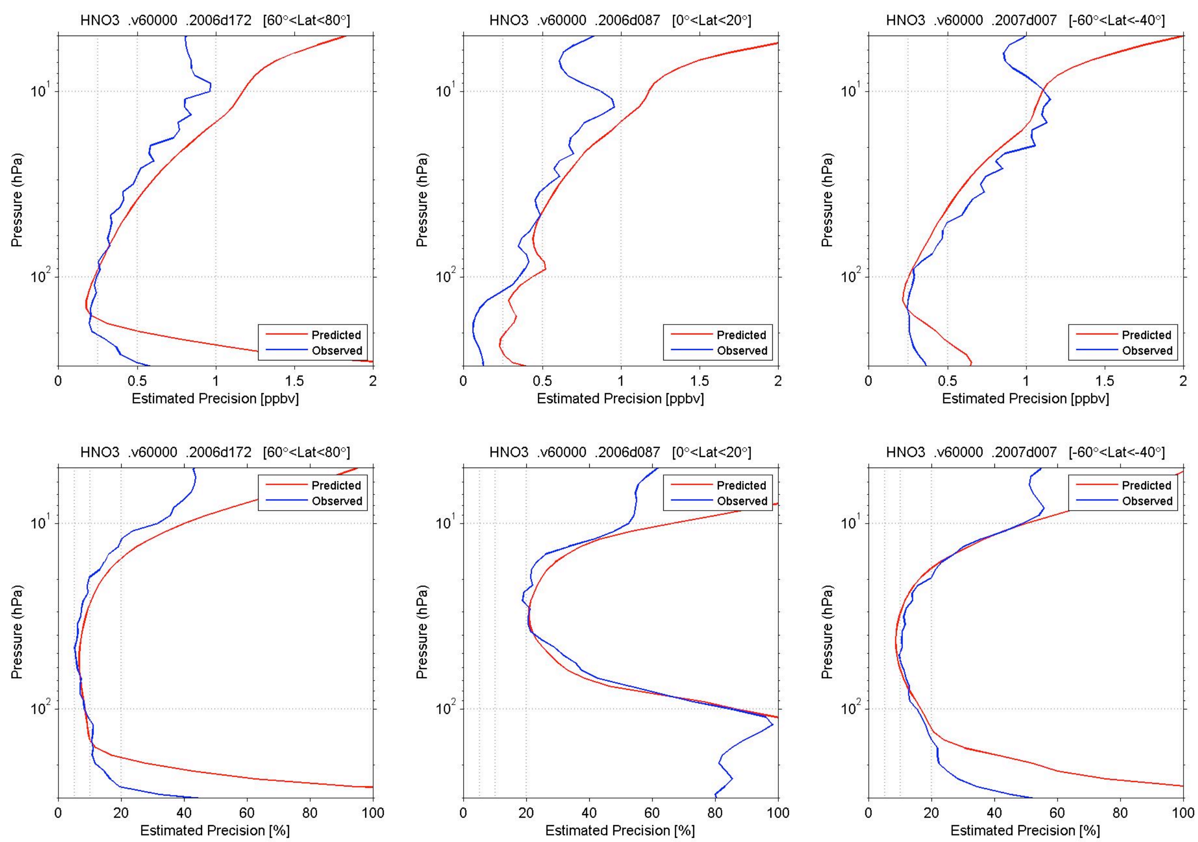


Figure 5.3.2: Shown are the predicted and observed HNO_3 precision. The 'predicted' precision (red) is that computed by the retrieval program, averaged over the indicated latitude band. Three representative latitude bands are shown: 60-80°N (left), 0-20°N (center), 60 - 40°S (right). The "observed" precision (blue) is computed as the average of the standard deviation of ten detrended sequences of 12 consecutive profiles in undisturbed regions (see Section 5). Precision is shown in volume mixing ratio (top row) and percent (bottom row).

Accuracy

The bias, in terms of mixing ratio and percentage, are determined primarily from comparisons with the version 3.3 Aura-MLS and the version 3 ACE-FTS global data sets.

Mid and High Latitudes. Comparisons with the MLS version 3.3 observations (Figure 5.3.3 and Figure 5.3.4) show that large-scale features are consistent between the two instruments and in good agreement at all latitudes. HIRDLS HNO_3 is biased low ≤15% relative to Aura MLS in the mid-to-high latitudes (≤20% at high southern latitudes) at most pressure levels in the useful range 7.5-215 hPa. An exception to this is that there can be a high bias (~10%) at 100-200 hPa in the northern mid-to-high latitudes. Above 10 hPa the bias is high and increases upward to about 50% at 7 hPa.

Comparisons with the ACE-FTS version 3 observations are very consistent with the MLS comparisons: there is a 0-15% low bias relative to ACE-FTS for the majority of the range 10-215 hPa, with an exception of a 20% high bias at 200 hPa at northern mid- latitudes. The low bias with respect to ACE-FTS is greater than for MLS near 10 hPa, at about 25%-50%.

Low Latitudes. Comparisons with both MLS and ACE-FTS are also consistent in the tropics. They indicate that the HIRDLS HNO_3 bias in the tropics is within ±10% between 15 – 50 hPa, negative at the top of the region and positive at the bottom. At the spaceward end of the tropical HNO_3 profiles, the HIRDLS bias with respect to MLS and ACE-FTS is negative 10-50%, increasing upward. HIRDLS HNO_3 is biased high 10-100+% at 50 hPa and below, increasing earthward, where mixing ratios are at the lowest levels observed. Note that a similar magnitude high bias is observed in this region in other HIRDLS measurements. These are believed to be caused by the presence of aerosols; a correction is being developed.

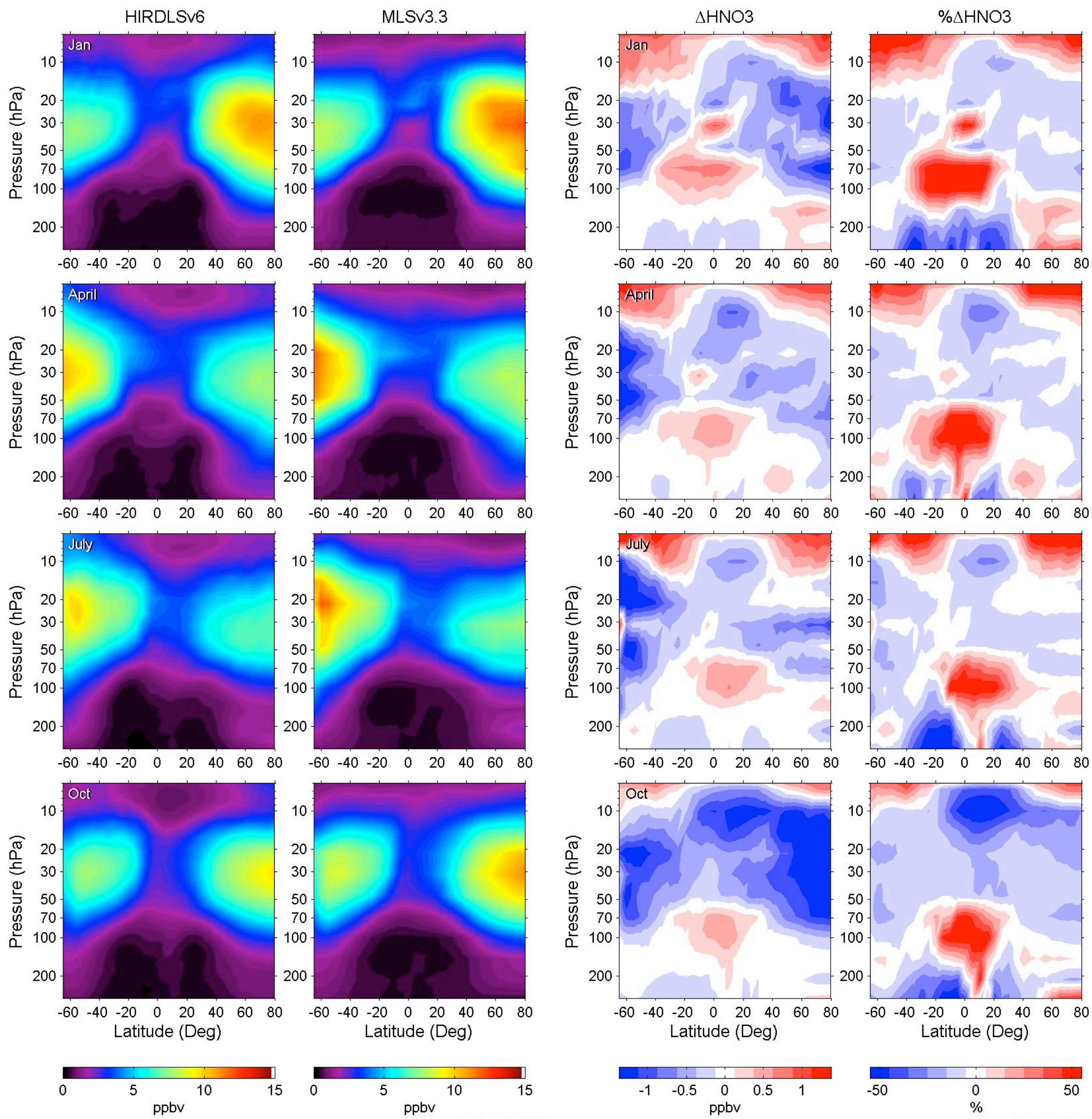


Figure 5.3.3. The two left columns are the monthly zonal mean cross sections for HIRDLS and MLS v3.3 HNO_3, in units of volume mixing ratio (ppmv), for the months in 2006 of January, April, July and October (as indicated at top left, inset, of each row). The mixing ratio difference and percentage difference (HIRDLS–MLS)/(MLS) are shown in the 3rd and last columns respectively. The white areas in the difference and percent difference plots correspond to 0 pptv ±125 pptv and 0%±5%, respectively; each blue and red color increment corresponds to a multiple of 250 pptv and 10%, respectively.

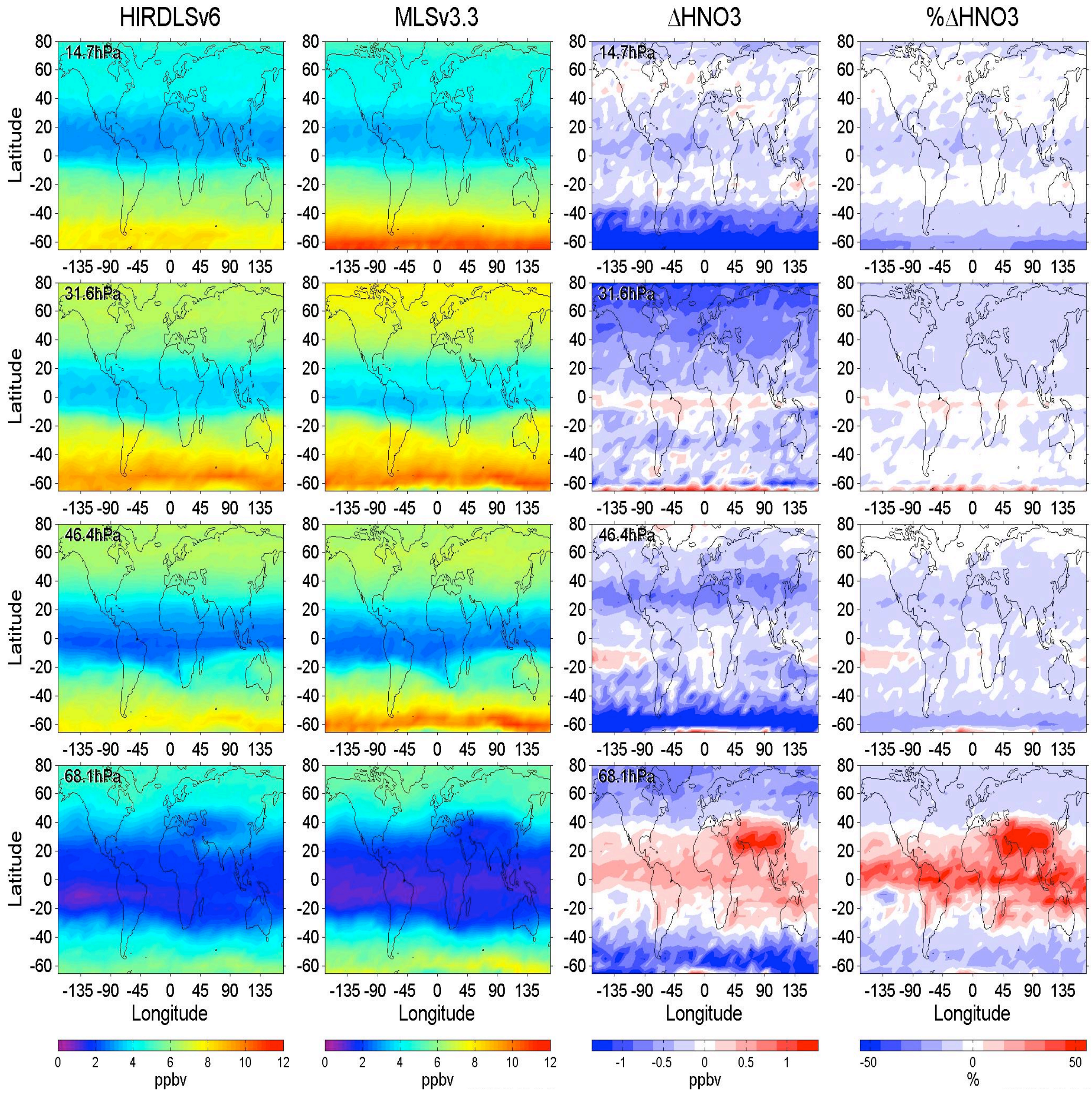


Figure 5.3.4. Shown are the longitude-latitude cross sections of HIRDLS and MLS HNO_3 (ppbv) for July 2006. The rows depict the average for the approximate pressure levels: 15 hPa, 31 hPa, 46 hPa and 68hPa, from top to bottom. The mixing ratio difference and percentage difference (HIRDLS–MLS)/(MLS) are shown in the 3rd and last columns respectively. The white areas in the difference and percent difference plots correspond to 0 pptv ±125 pptv and 0%±5%, respectively; each blue and red color increment corresponds to a multiple of 250 pptv and 10%, respectively.

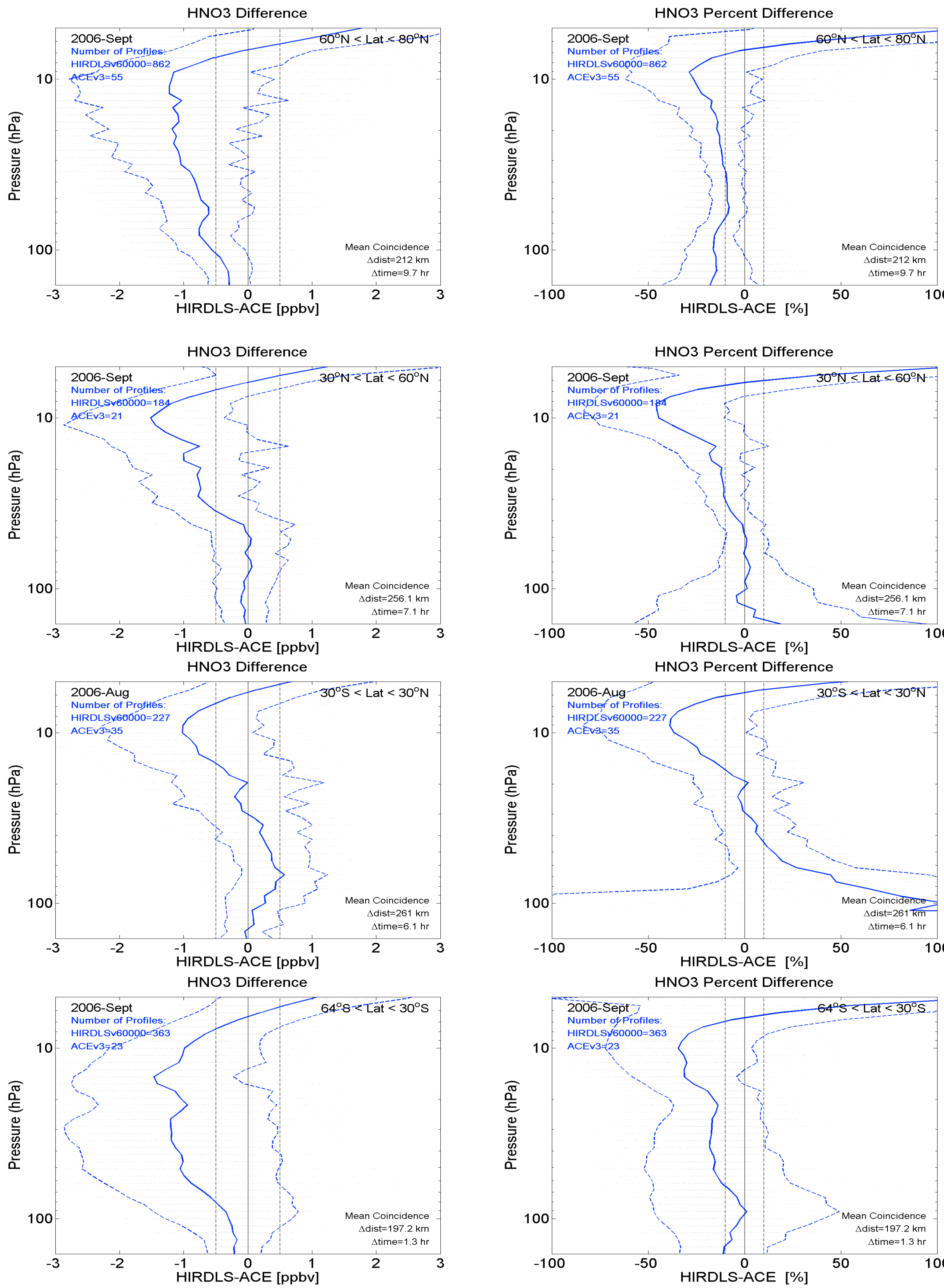


Figure 5.3.5. Shown are mean HNO_3 differences (solid blue lines) from comparisons with ACE-FTS v3 measurements. Results for coincidences during the month of September 2006 are shown for high latitudes (60-80°N, top), for the mid-northern latitudes (30-60°N, 2nd row) and for the mid-southern latitudes (30-64°S, bottom). Results for coincidences during the month of August 2006 are shown for low latitudes (30°S-30°N, 3rd row). The plots are in units of volume mixing ratio (left) and percentage difference (right). The dashed blue lines are the standard deviation of differences.

Summary

The Nitric Acid data have a vertical resolution of 1 km. From 10 to 215 hPa the observed precision is between 0.1 – 1.0 ppbv, increasing spaceward. Percentage error will vary, depending on HNO_3 abundance. HIRDLS HNO_3 data are generally good over the full latitude range of 64ºS to 80ºN and pressure range ~100 hPa to 10 hPa, with some profiles, depending on latitude, having useful information between 100 hPa to 215 hPa. The upper limit is determined by the falling signal to noise (S/N) with altitude, while the lower limit is determined by very low mixing ratios in the troposphere.

5.4 CFC11, CFC 12

Species:	CFC11 ($CFCl_3$), CFC12 (CF_2Cl_2)
Data Field Names:	CFC11, CFC12
Useful Ranges:	CFC11 316 hPa - 26.1 hPa CFC12 316 hPa - 10.0 hPa
Screening Criteria:	Use with caution: Data points with negative precisions Data points with cloud flag ≠ 0 - data should not be used CFC 11 data above surface value (approx. 250pptv) CFC 12 data above surface value (approx. 540pptv)
Vertical Resolution:	~1 km
Contact:	Bruno Nardi
Email:	nardi@ucar.edu
Validation Paper:	Coffey, M., et al., Validation of HIRDLS CFC11 and CFC12 Observations, *In preparation*.

General Comments

This section will describe HIRDLS observations of CFC11 ($CFCl_3$) and CFC12 (CF_2Cl_2). These anthropogenic gases have common sources, distributions and chemistry in the atmosphere and will be discussed together here.

Resolution

Vertical resolution of the CFC observations is described by the vertical averaging kernel and is shown in Figure 5.4.1. There is some variation in the vertical resolution with latitude but that variation is small within the useful pressure range. As may be seen in Figure 5.4.1 the vertical resolution for both CFC11 and CFC12, over the useful pressure range, is 1.0-1.2 km. The horizontal resolution of the observations is approximately 100 km along an orbit track with an orbital separation of about 24.75° of longitude (about 2000 km at 40°N, see Section 2.2.2).

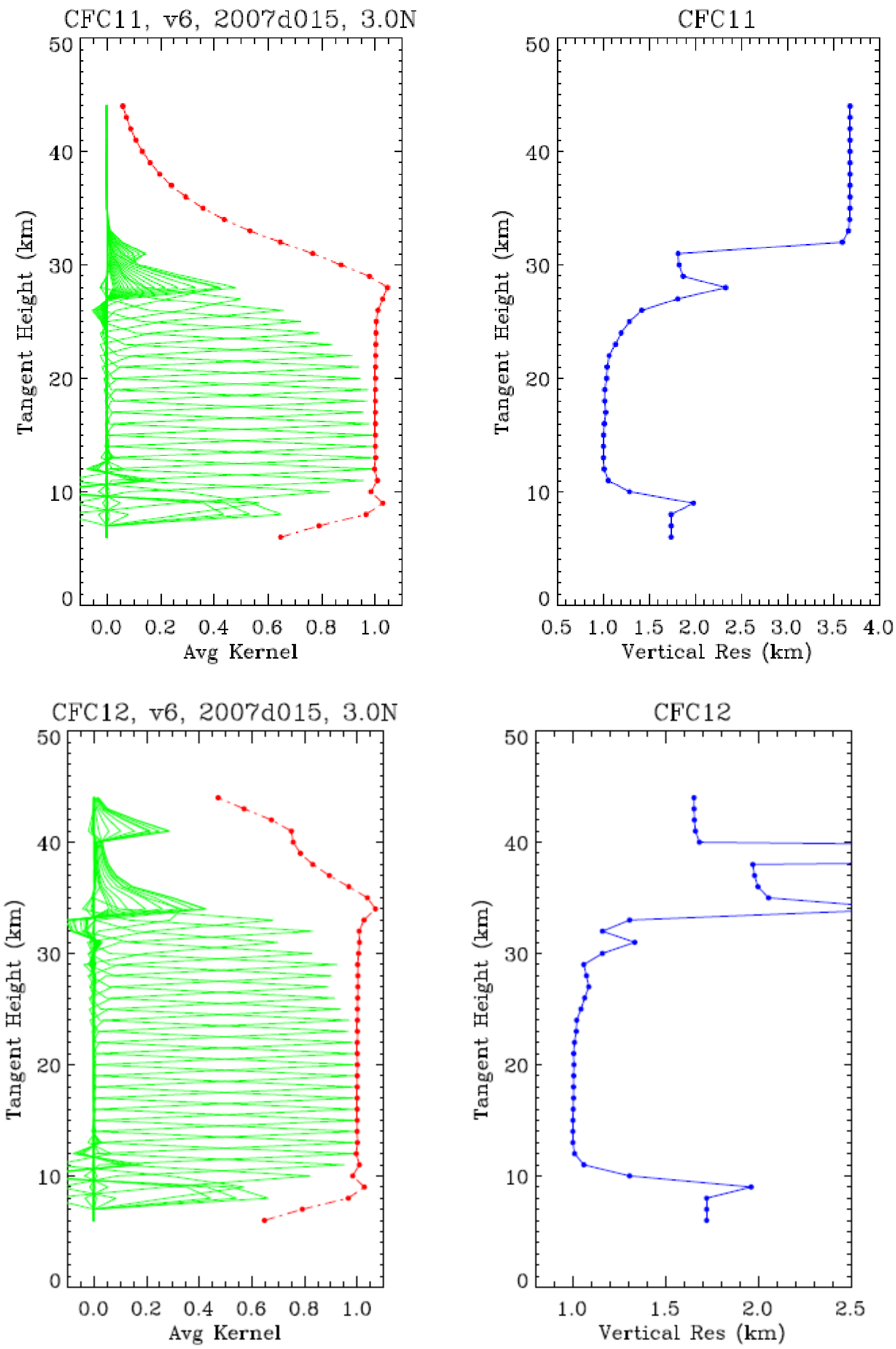


Figure 5.4.1. Shown are the HIRDLS averaging kernels (left) and vertical resolution profiles (right, full width half maximum, FWHM) for CFC11 (top) and CFC12 (bottom). The averaging kernels (green lines) and the integrated area under each kernel (red line) are shown. Values of unity indicate that the entire signal for that vertical region comes from the measurement and not from a priori information. The vertical resolution versus tangent height is derived from the FWHM of each kernel (blue line).

Precision

The predicted and observed precision for CFC11 and CFC12 are shown in Figures 5.4.2 and 5.4.3 respectively. The observed precision (blue line) is estimated from the average of 10 sets of rms differences from trend lines through 12 sequential profiles in undisturbed regions (See Section 5.0). The plots indicate precisions of 0.015-0.03 ppbv for CFC11 and 0.03-0.1 ppbv for CFC12, somewhat better than the predicted precision (red line) calculated by the retrieval program. These values correspond to uncertainties of 5-20% over much of the useful range, and roughly 20-100% at the upper range of the profiles.

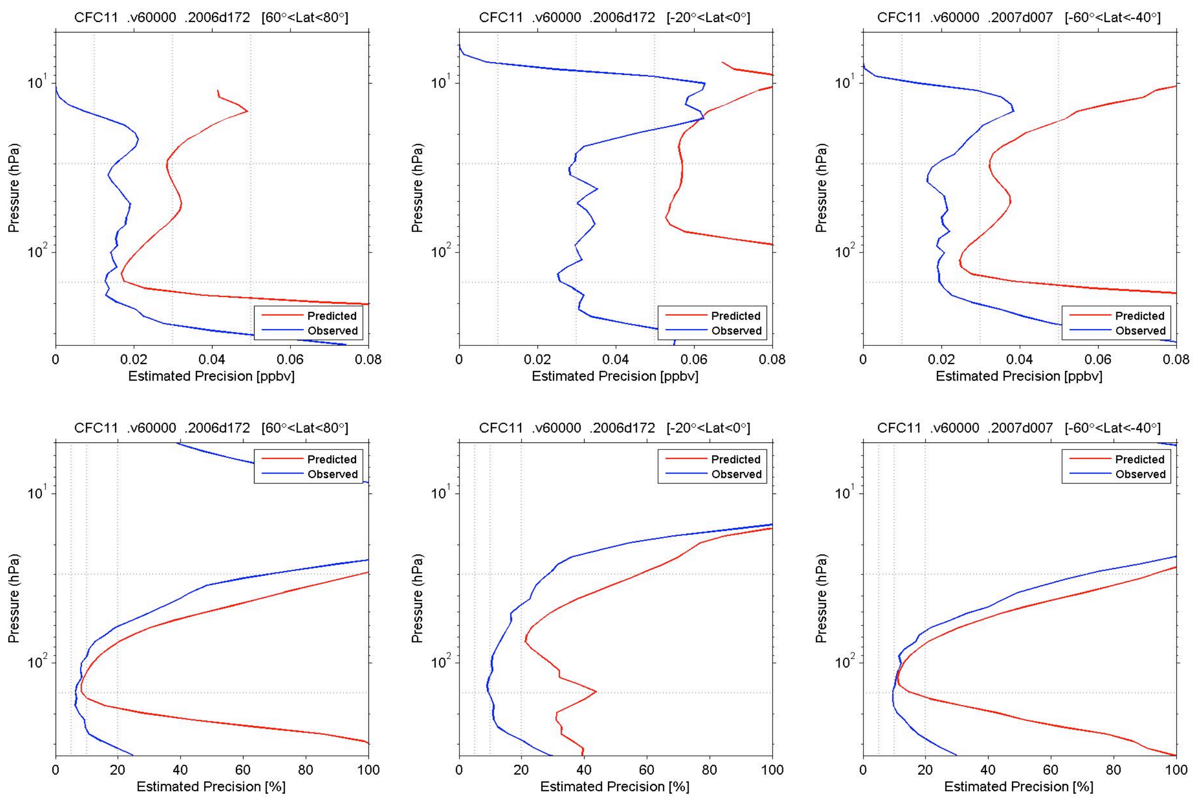


Figure 5.4.2. Shown are the predicted and observed CFC-11 precision. The 'predicted' precision (red) is that computed by the retrieval program, averaged over the indicated latitude band. Three representative latitude bands are shown: 60-80°N (left), 0-20°N (center), 60 - 40°S (right). The "observed" precision (blue) is computed as the average of ten rms differences from detrended sequences of 12 consecutive profiles in undisturbed regions (see Section 5). Precision is shown in volume mixing ratio (top row) and percent (bottom row).

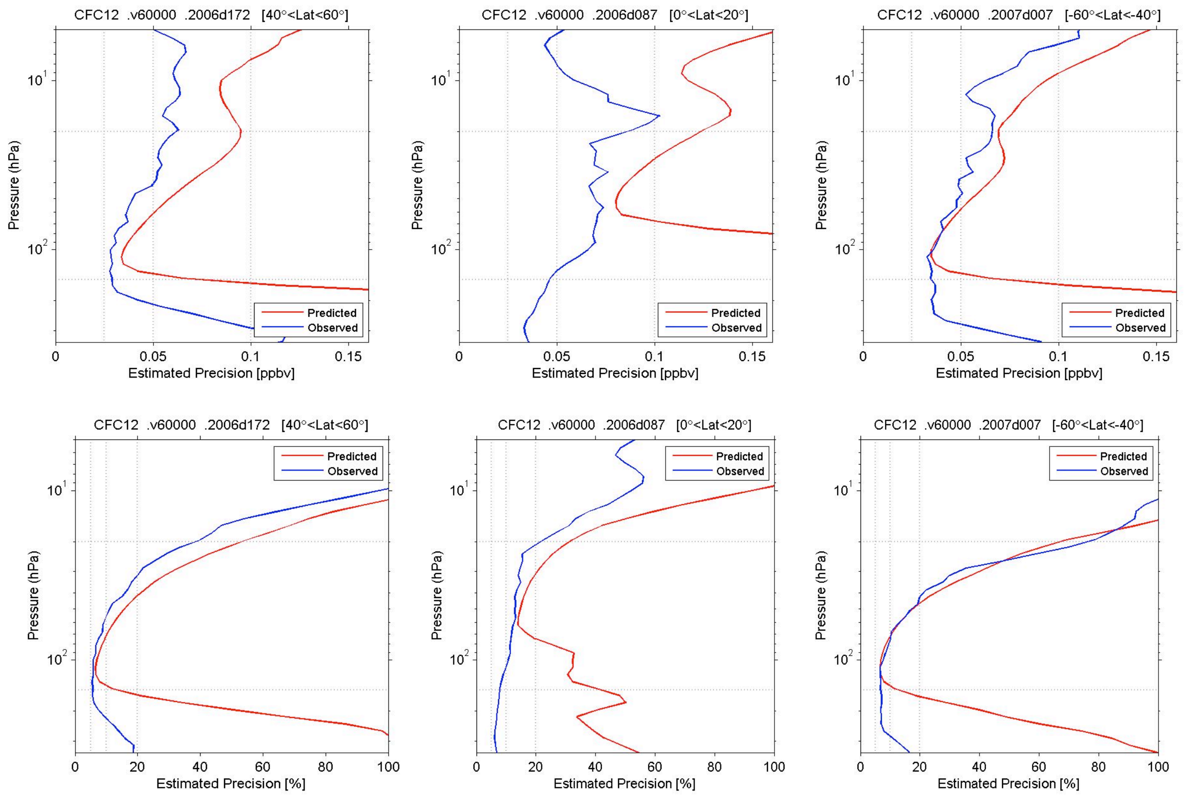


Figure 5.4.3. The precision estimated for CFC12. The same format is used as for CFC-11 above.

Accuracy

Comparisons are made with a number of other global observations of CFC11 and CFC12, including ACE-FTS, Envisat-Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), Atmospheric Trace Molecule Spectroscopy (ATMOS), Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA), MIPAS and JPL MkIV.

Figure 5.4.4 shows a daily zonal mean cross-section of CFC11 and CFC12 for 18 May 2006. The lifetimes of CFC11 and CFC12 in the atmosphere are relatively long (approximately 50 and 100 years respectively). Thus we may expect the tropospheric amounts of the CFCs to be fairly uniform with the same magnitude as the surface value. Surface observations of CFCs have been made by NOAA [Elkins et al., 1993] for many years and show a slowly varying mixing ratio with time. CFC11 surface values, from stations at latitudes from 71°N to 90°S, in 2006 ranged from 248 to 252 pptv; for CFC12, for the same stations and times, surface amounts were 530-540 pptv. As may be seen in Figure 5.4.4 the tropospheric amounts retrieved by HIRDLS are similar to those measured from the NOAA surface stations. There is a regularly observed excess of CFC11 and CFC12, of about 15% and 25% respectively, in the upper tropical troposphere, whose origin is probably caused by the presence of aerosols which are not included in the present retrieval.

Figure 5.4.5 shows the CFC11 and CFC12 vertical mixing ratio profiles from HIRDLS and from a number of satellite and balloon-borne instruments. The satellite results are reported in Hoffmann et al, [2008], the latest results being from the space-borne MIPAS instrument on Envisat for 2002-2004. Care must be taken in comparing the older satellite observations with HIRDLS since both CFC11 and CFC12 show a clear temporal change. CFC11 surface mixing ratio increased steadily until about 1995 and has shown an average of 2% per year decrease since then. The CFC12 amount, with a longer lifetime, leveled off around 2003.

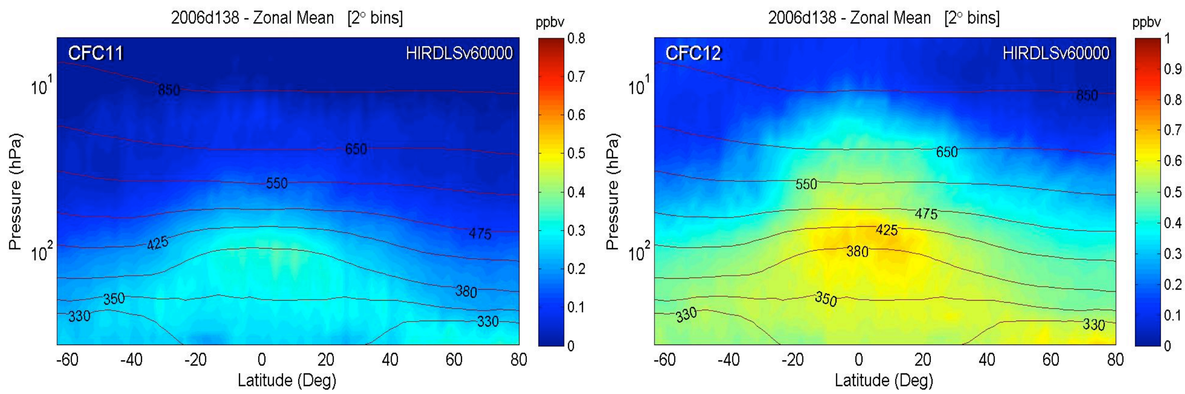


Figure 5.4.4. Shown are the zonal mean cross-sections of CFC11 and CFC12 mixing ratios on 18 May 2006. The region of high values in the tropical UTLS may be an effect of aerosols not included in the retrieval process. The black contour lines show the potential temperature surfaces (units, K).

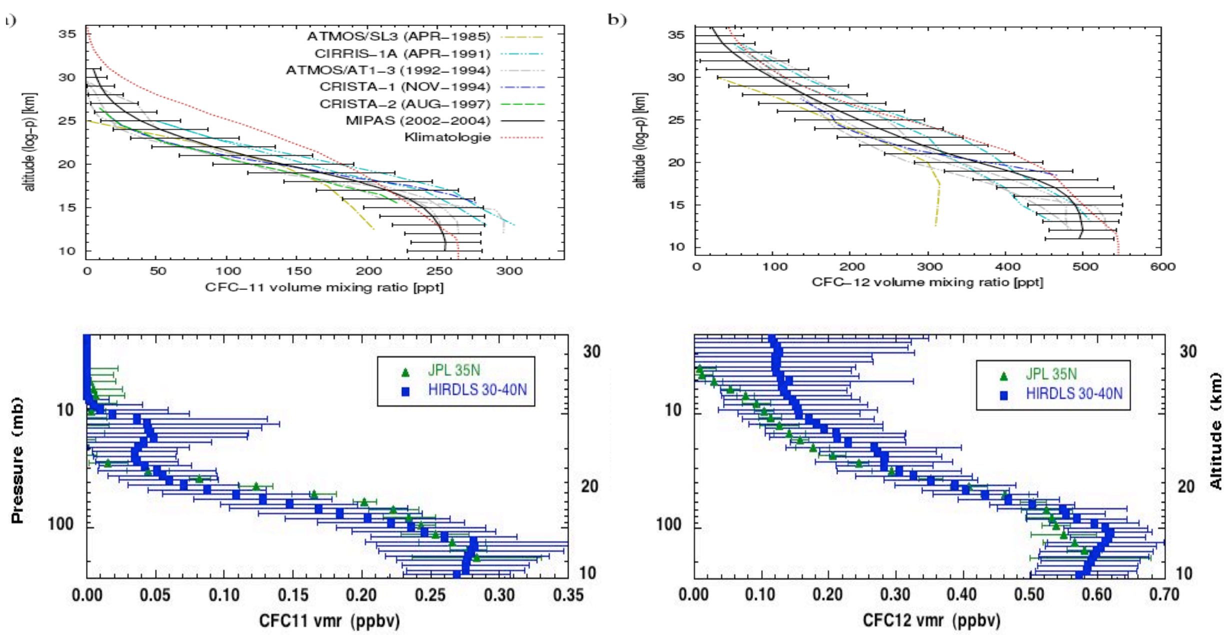


Figure 5.4.5. Shown are vertical profiles of CFC11 and CFC12 mixing ratios from a number of satellite and balloon experiments (ATMOS, CIRRIS, CRISTA, MIPAS, JPL MkIV) and from HIRDLS. Observations are all from northern hemisphere mid-latitudes.

Two satellite-borne experiments that report measurements of CFC11 and CFC12 are the MIPAS instrument aboard Envisat (launched in March 2002) and ACE aboard SciSat (launched in August 2003).

Figure 5.4.6 compares the monthly zonal mean of CFC11 and CFC12 for HIRDLS and MIPAS for July 2006. The CFC11 bias is within ±10% with respect to MIPAS for most of the useful range (26-316 hPa) outside the tropical UTLS, where high values noted above can be seen clearly to reach 25%. The low bias at high southern latitudes appears to be a MIPAS artifact. Above the useful range at 26 hPa the bias is high and increases rapidly upward. The HIRDLS CFC12 has a high bias of <10% with respect to MIPAS between 30-316 hPa at mid and high latitudes, except earthward of 150 hPa in the northern hemisphere, where it is <20%. In the tropical UTLS, the bias with respect to MIPAS reaches a high value of 40%. Above about 30 hPa the bias is high, and it increases upward to >50% at 10 hPa.

Figures 5.4.7 and 5.4.8 show the mean bias of HIRDLS CFC11 and CFC12 with respect to the ACE-FTS v3. All coincidences within 500 km and 12 hours are used within the four latitude regions for the months of August and September 2006, as indicated on the plots. There is very good agreement, of better than 10% for most of the useful range for both species for all regions, except in the tropical UTLS as noted above, where the bias is positive 15% and 25%. At the upper extreme of the profiles (26 hPa for CFC11, and 10 hPa for CFC12), for all regions, there is an increasingly high bias approaching values of roughly 50 pptv for both species. These coincide with the rapid degradation of the precision seen in Figures 5.4.2 and 5.4.3.

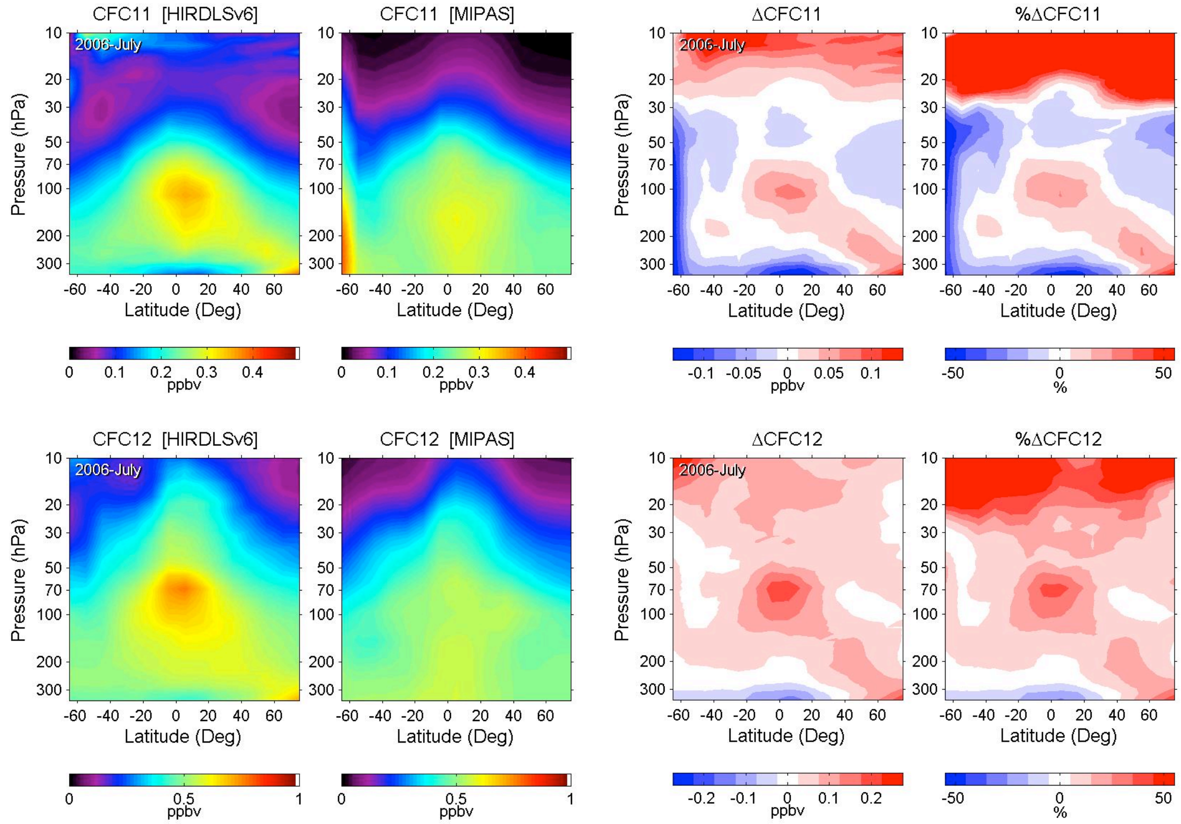


Figure 5.4.6. Monthly zonal mean cross-sections of CFC11 (top) and CFC12 (bottom) mixing ratios as measured on July 2006 by HIRDLS (1st column) and MIPAS (2nd column). The mixing ratio difference and percentage difference (HIRDLS–MIPAS)/(MIPAS) are shown in the 3rd and last columns. The white areas in the difference and %-difference plots correspond to 0±25 pptv and 0%±5%, respectively; each blue and red color increment corresponds to an increment of 50 pptv and 10%, respectively. The southern high latitude feature in CFC11 is due to a non-geophysical artifact in the MIPAS zonal mean.

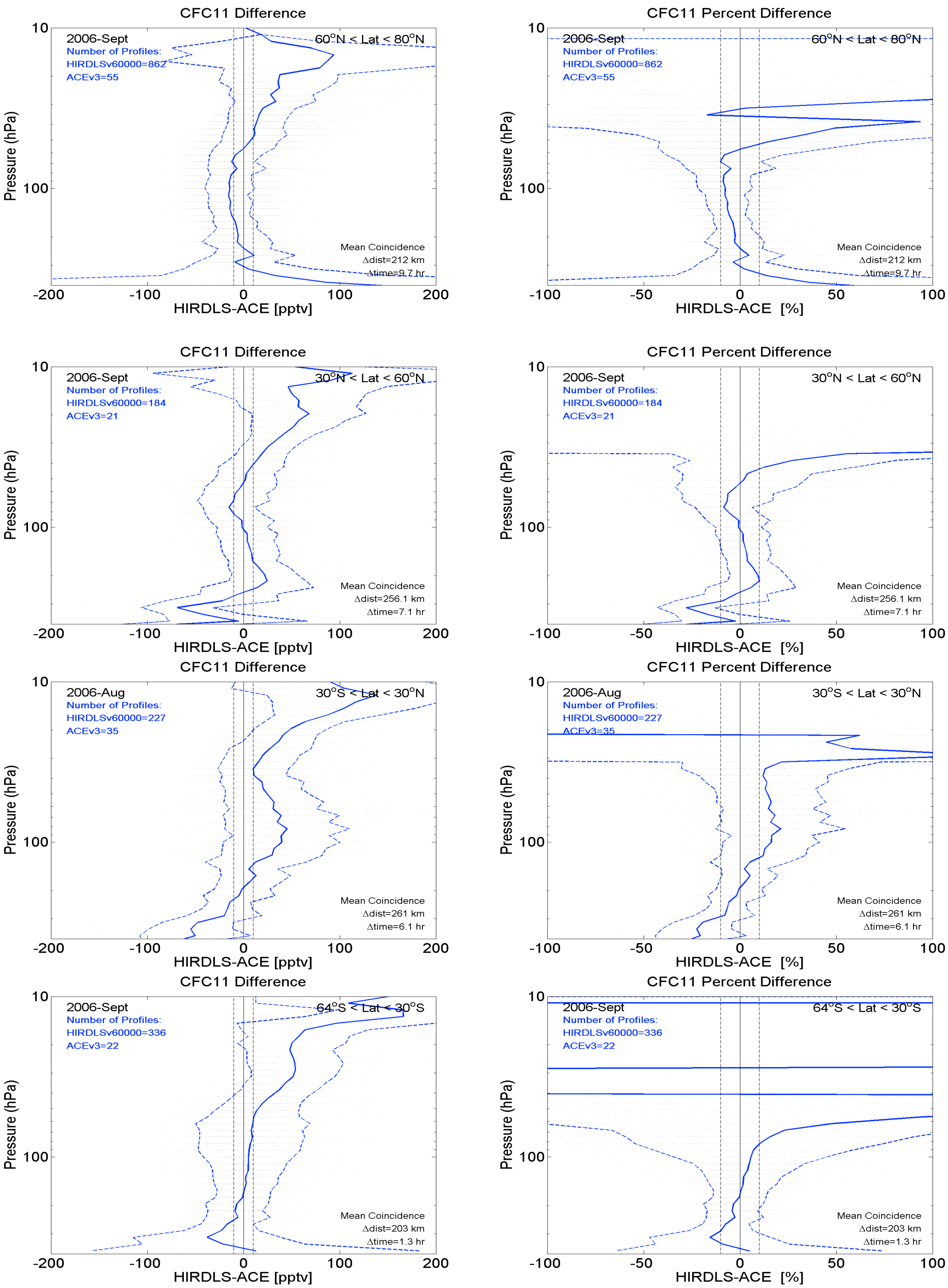


Figure 5.4.7. Shown are mean CFC11 mixing ratios differences (solid blue lines) from comparisons with ACE-FTS v3 measurements. Results for coincidences during the month of September 2006 are shown for high latitudes (60-80°N, top), for the mid-northern latitudes (30-60°N, 2nd row) and for the mid-southern latitudes (30-64°S, bottom). Results for coincidences during the month of August 2006 are shown for low latitudes (30°S-30°N, 3rd row). The plots are in units of volume mixing ratio (left) and percentage difference (right). The dashed blue lines are the standard deviation of differences. The mean coincidence criteria is inset in the bottom right of the plots.

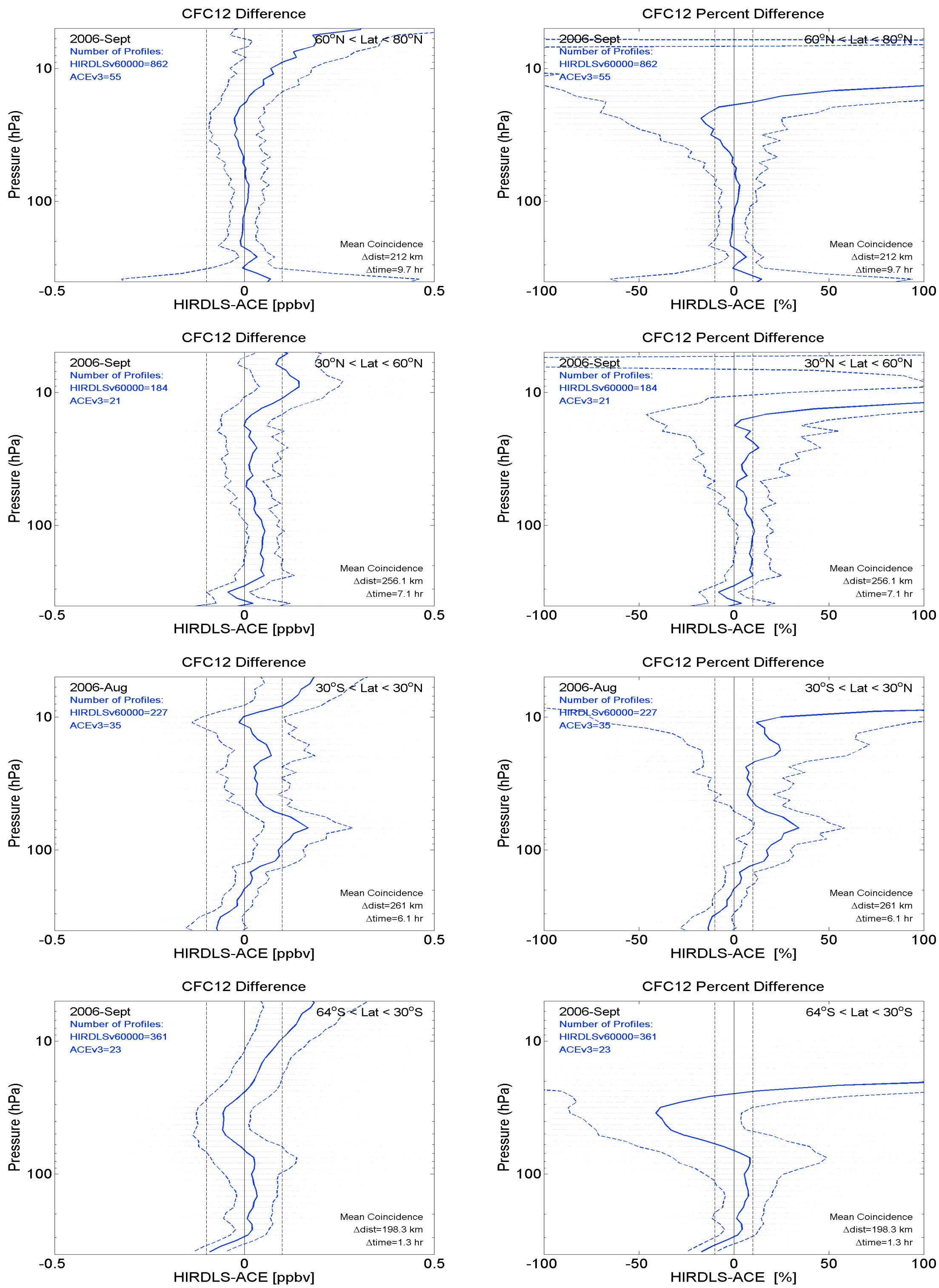


Figure 5.4.8: Shown are mean CFC12 mixing ratios differences (solid blue lines) from comparisons with ACE-FTS v3 measurements. Results for coincidences during the month of September 2006 are shown for high latitudes (60-80°N, top), for the mid-northern latitudes (30-60°N, 2nd row) and for the mid-southern latitudes (30-64°S, bottom). Results for coincidences during the month of August 2006 are shown for low latitudes (30°S-30°N, 3rd row). The plots are in units of volume mixing ratio (left) and percentage difference (right). The dashed blue lines are the standard deviation of differences. The mean coincidence criteria is inset in the bottom right of the plots.

Summary

CFC's have a vertical resolution of 1 km, with precisions of ~ 0.02 ppbv or 10% (CFC11) and ~ 0.05 ppbv or 10% (CFC12), although both vary significantly with altitude. HIRDLS CFC measurements are generally useful between latitudes of 63°S to 80°N and within pressure ranges of 26.1 – 316 hPa (about 10 to 25 km) for CFC11 and 10 – 316 hPa (about 10 to 31 km) for CFC12. It should be noted that data outside of the useful range have been eliminated from the publicly released data.

*5.5 Water ($H2O$)**

*To be supplied

*5.6 Methane ($CH4$)**

*To be supplied

5.7 Nitrogen Dioxide (NO2)

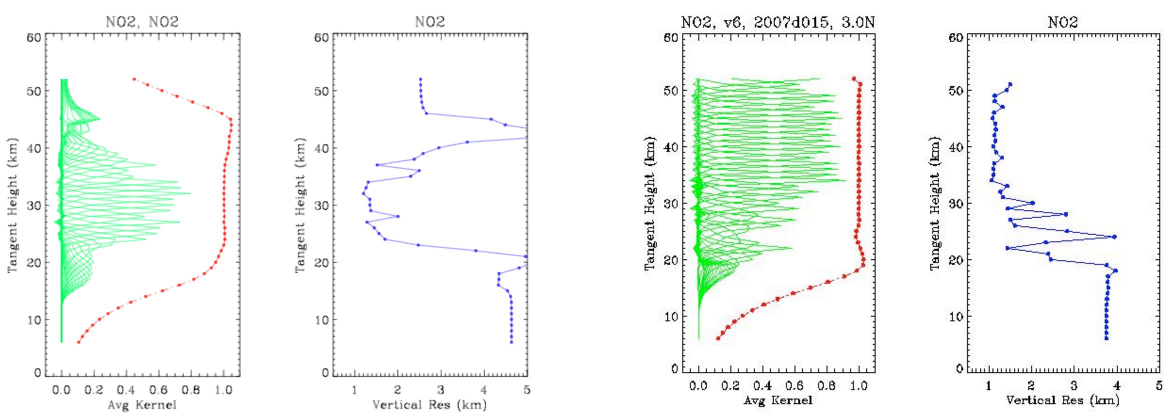
Species:	Nitrogen Dioxide (NO_2)
Data Field Name:	NO2Day NO2Night
Useful Range:	Daytime (56.2 to 1.0 hPa) Nighttime (56.2 to 0.75 hPa)
Screening criteria:	Use with caution: Data outside of the June 2005 – June 2006 period.
Vertical Resolution:	1.2 km
Contact:	Maria Belmonte Rivas
Email:	rivasm@ucar.edu
Validation paper:	In preparation

General Comments

The daily HIRDLS NO_2 zonal means are extracted from the zeroth order zonal coefficient of the synoptic fields estimated by a Kalman filter (as described in Section 4.5) applied to measured NO_2 profiles from down-scans. The zonal means are split into daytime (solar zenith angle SZA < 90°) and nighttime (SZA > 100°) products using a latitude grid spacing of 2°. The local solar time (LST) of the zonal mean is a function of latitude, as shown in the left plot on Figure 5.7.3.

Resolution

The HIRDLS NO_2 vertical resolution is approximately 1 km at peak Volume Mixing Ratio (VMR) levels as determined from the full-width at half maximum of the averaging kernels shown in Figure 5.7.1 (daytime on left, nighttime on right), decreasing to 2 - 4 km as the NO_2 mixing ratio approaches zero at the upper and lower ends of the trace gas profile.



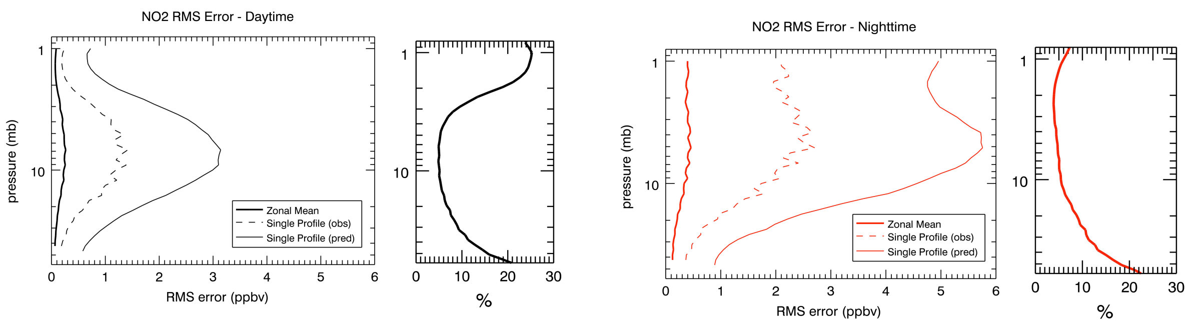
Daytime Nighttime

Figure 5.7.1. Averaging kernels (green lines) and vertical resolution (blue curves) as a function of altitude for daytime (left) and nighttime (right) HIRDLS NO_2 zonal means.

Recall that the red line on the left panels indicate the fraction of the information that comes from the HIRDLS measurements; values close to unity indicate that there is negligible influence from the a priori. The daytime (nighttime) averaging kernels were calculated for 15 January 2007 at 45°N (3°N) with a cloud top altitude of 8 km: any latitudinal variations should be small over regions with large signal to noise ratio (SNR).

Precision

The estimated precision of the HIRDLS Kalman filtered NO_2 zonal means is displayed in Figure 5.7.2 along with the predicted and observed uncertainties of the raw profile data. The observed uncertainty is derived from the dispersion of raw data about the Kalman filtered zonal mean. The ratio of raw profile to zonal mean precision is commensurate with the squared root of the number of profiles *N* assimilated by the Kalman filter per latitude bin per day (N~ 50). The estimated precision of the NO_2 zonal means is < 0.2 (0.4) ppbv for the day (night) products, reflecting the difference in the size of the signal and thus SNR between day and night.



Daytime Nighttime

Figure 5.7.2. Estimated precision of the HIRDLS V6 Kalman filtered NO_2 zonal means (thick solid lines) compared with the observed and predicted precision of original profile data (dashed lines and thin solid line).

Accuracy

In order to arrive at an estimate of absolute bias, the HIRDLS Kalman filtered NO_2 zonal means have been compared to independent MIPAS and ACE-FTS datasets. Because NO_2 exhibits a strong diurnal cycle, a photochemical model has been introduced to correct for differences in local observation times between HIRDLS and the validating instruments.

NO_2 is a short-lived species in photochemical equilibrium with NO and N_2O_5, featuring a smooth profile with minimum (maximum) mixing ratios after sunrise (sunset) and a broad peak between 3 and 10 hPa (30-40 km) as shown in Figures 5.7.4 and 5.7.5. The photochemical model correction is effected through the ratio of modeled NO_2 profiles evaluated at the appropriate latitude (*lat*) and observation times (*LST, LST₀*):

$$VMR(z,lat,doy,LST) = VMR(z,lat,doy,LST_0)\cdot\frac{VMR_{model}(z,lat,doy,LST)}{VMR_{model}(z,lat,doy,LST_0)}$$

Where *z* refers to altitude and *doy* to day of the year. The photochemical correction to ACE-FTS profiles is based on the UCI (University of California at Irvine) photochemical box model described in Prather, [1997] and McLinden, [2000], and shown in Figure 5.7.4. The photochemical correction to MIPAS profiles is based on the SD-WACCM model described below and shown in Figure 5.7.5. Uncertainties introduced into the diurnally shifted profiles are expected to be small, generally less than 10% in the middle stratosphere and 20% in the lower/upper stratosphere. Major uncertainties are expected to occur at extreme high latitudes.

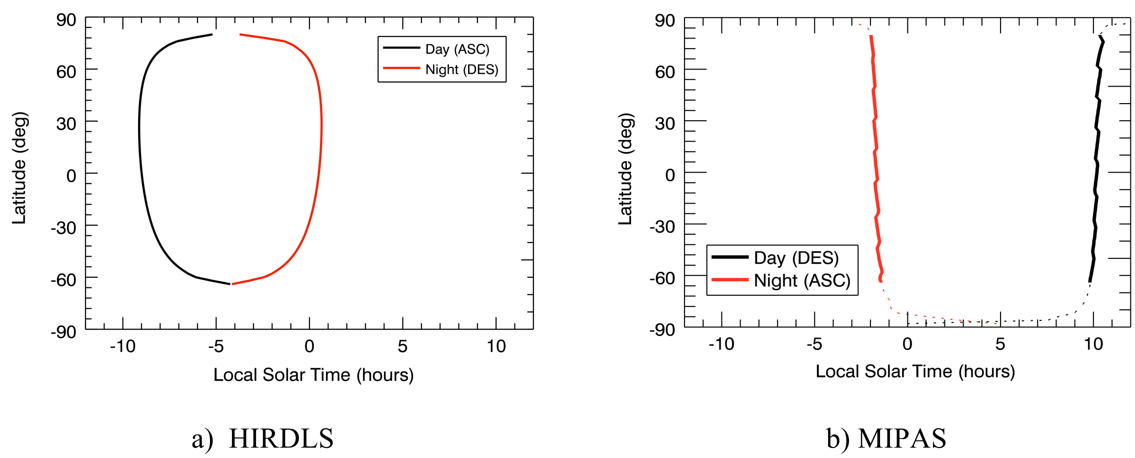


Figure 5.7.3. Daytime and nightime local solar times (LST) of the HIRDLS (left) and MIPAS (right) NO_2 zonal means.

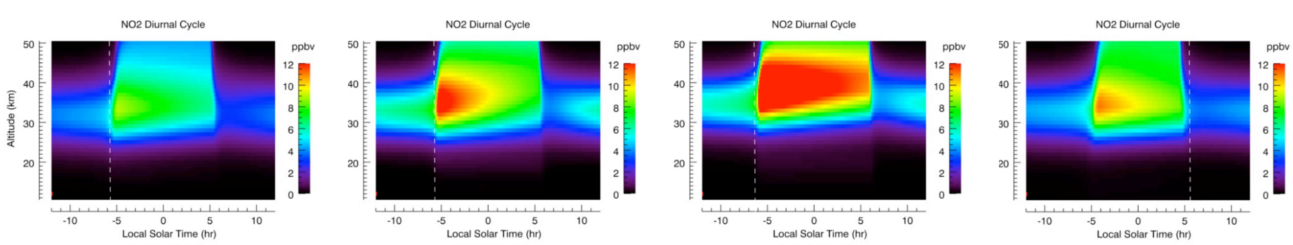


Figure 5.7.4. Diurnal variation of NO_2 (March 21st 2005) from ACE photochemical box model

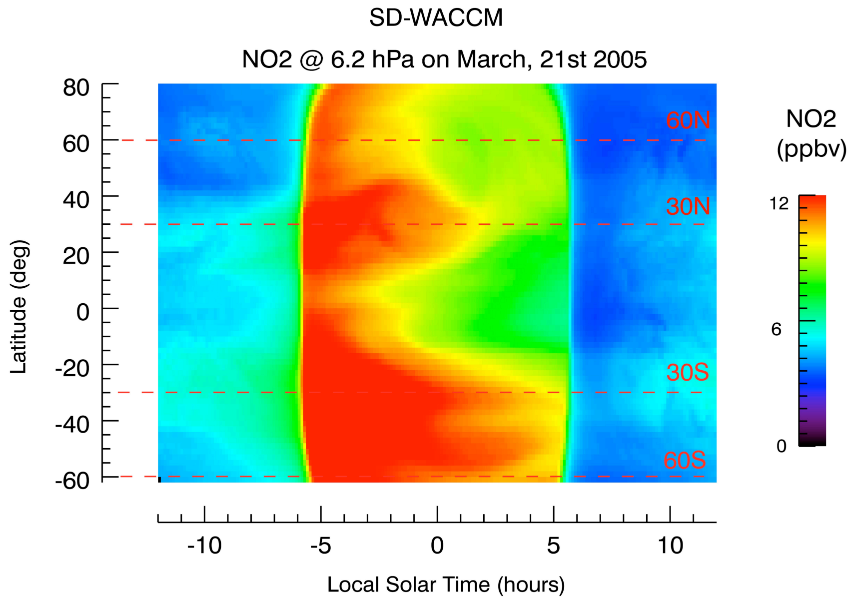


Figure 5.7.5. Diurnal variation of NO_2 (March 21st 2005) from SD-WACCM at peak VMR pressure level

Validation Datasets

MIPAS is a limb-sounding Fourier transform spectrometer collecting emission from the atmosphere in the mid-infrared. It measures NO_2 from 6 to 68 km with a vertical resolution of 3.5 to 6.5 km (the latter above 2 hPa). The MIPAS platform flies in a circular orbit at an altitude of 800 km with an inclination of 98.5 deg and descending node at 10.00 (local time), circling the Earth about 14 times a day and collecting profiles every 500 km along the orbit. In this comparison, we use MIPAS NO_2 zonal means from profiles retrieved using the IMK-IAA processor (Instituut fur Meteorologie und Klimaforschung – Instituto de Astrofisica de Andalucia, version V40) described in von Clarmann, [2003].

A comparison of MIPAS NO2 profiles with correlative measurements (i.e. ground based, HALOE, SAGE II, POAM III and ACE-FTS) indicate that MIPAS provides valuable information from 2 to 30 hPa (25 to 45 km) during day and night with an overall accuracy better than 30% and a precision of 5-15%, with degraded accuracy during perturbed conditions (i.e. strong subsidence of NO_2>100 ppbv in the polar winter mesosphere) (Wetzel, [2007]).

The **ACE-FTS** instrument records solar occultation spectra in the infrared. The ACE-FTS platform flies in a circular orbit at an altitude of 650 km with an inclination of 74 deg, providing up to 15 sunrise and 15 sunset solar occulations per day over an annually repeating coverage pattern. It measures NO_2 from 13 to 58 km with a vertical resolution of 3-4 km [Boone, 2005]. In this comparison we use the ACE-FTS sunset and sunrise zonal means using the Version 2.2 retrieved profiles.

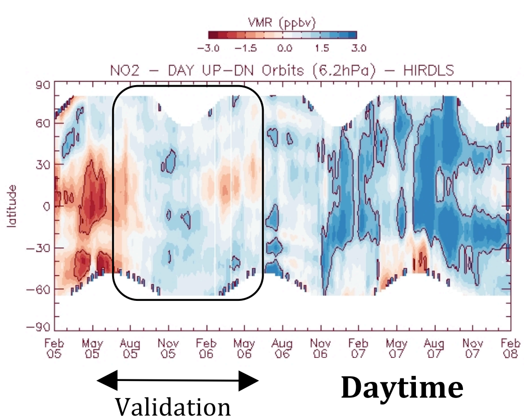
The retrieved ACE-FTS NO_2 profiles agree with other satellite datasets (ground based, Halogen Occultation Experiment [HALOE], Stratospheric Aerosol and Gas Experiment [SAGE III], Polar Ozone and Aerosol Measurement [POAM III], Scanning Imaging

Absorption Spectrometer for Atmospheric Cartography [SCIAMACHY], Optical System for Imaging and Low-intermediate Resolution Integrated Spectroscopy [OSIRIS], MIPAS) to about 15% from 3 to 30 hPa (25 to 40 km) with a precision of 3% from 20 to 40 km, and inconclusive results for altitudes above 40 km or below 25 km (Kerzenmacher, [2008]). The ACE-FTS validation of NO_2 is overall compelling, with mean absolute differences to correlative measurements within 1 ppbv between 25 and 40 km, with the sole exception of MIPAS, which appears to be biased high (low) by up to 30% relative to ACE-FTS above (below) 10 hPa.

The **SD-WACCM** (Specified Dynamics Whole Atmosphere Community Climate Model, Version 3) is a full global climate model with chemistry based on the Community Atmospheric Model (CAM), featuring 66 vertical levels from the ground to approximately 145 km, and all the physical parameterizations described in Collins, [2004]. The dynamical fields of temperature and wind are specified by Goddard Earth Observing System (GEOS-5) reanalyses [Rieneker, 2008]. The gravity wave drag and vertical diffusion parameterizations are as described in Garcia, [2007]. WACCM3 has a detailed neutral chemistry module for the middle atmosphere, including diurnal cycles for all constituents at all levels in the model's domain, as described in Kinnison, [2007]. Vertical resolution is ≤1.5 km between the surface and about 25 km, increasing to 2 km at the stratopause and 3.5 km in the mesosphere. The latitude and longitude grids have spacing of 1.9 and 2.5 degrees, respectively. The SD-WACCM model results can be considered informative, but not strictly conducive to validation.

Up/down-Scan Agreement

Any preliminary quality test to the Kalman filtered NO_2 zonal means should include a comparison of the fields produced for its up-scans and down-scans. The algorithm for Kapton removal performs up and down-scan corrections in an independent fashion, so differences between these modes should give a first order estimate of the systematic errors associated with the Kapton correction. The up/down-scan NO_2 zonal mean differences are displayed in Figure 5.7.6 for day and night products at representative peak VMR pressure levels for the entire duration of the mission.



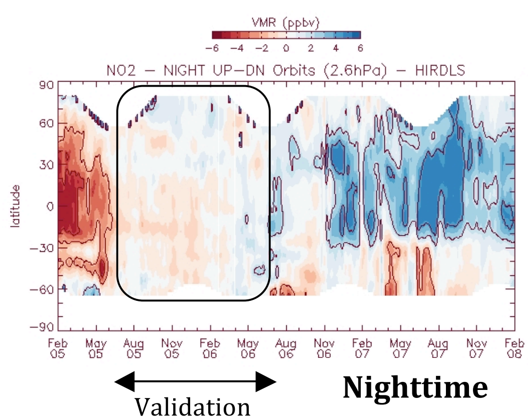
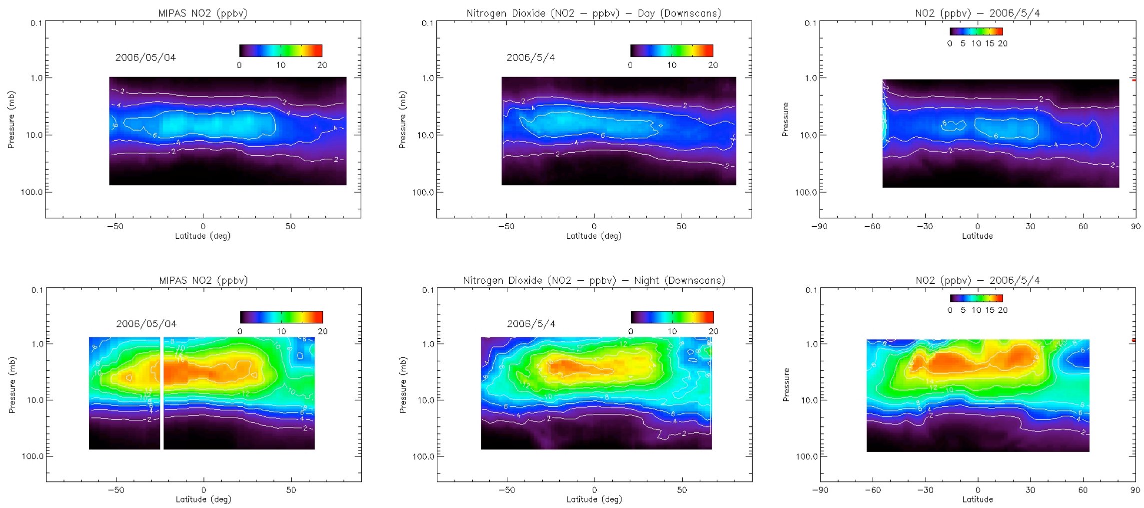


Figure 5.7.6. Up/down-scan differences for day (left) and night (right) NO_2 zonal means.

The combined up/down-scan differences provide a bias estimate of ~0.5 ppbv (1-sigma) for daytime (10% at 6.2hPa) and nighttime (5% at 2.6hPa) products over the Jun'05-Jun'06 window, which we denote the validation period. Outside of the validation period, systematic errors in the HIRDLS NO_2 zonal means can be as high as 50% at VMR peak levels. A representative comparison between the NO_2 zonal means from HIRDLS, MIPAS and the SD-WACCM model during the validation period (May 4th 2006) is shown in Fgure 5.7.7.



MIPAS HIRDLS SD-WACCM

Figure 5.7.7. Sample NO_2 zonalmeans for daytime (top) and nighttime (bottom) from MIPAS (left), HIRDLS (center) and SD-WACCM (right) – time corrected to HIRDLS observation time.

The systematic error analysis that follows is based on the comparison of HIRDLS with MIPAS and ACE-FTS zonal mean observations time-corrected to HIRDLS measurement times and collected over the validation period, from June 2005 through June 2006. The collocation consists of simple latitude matching, with MIPAS and ACE-FTS each having about 14 profiles per latitude bin. The reference profiles have been linearly interpolated to the HIRDLS altitude grid, without averaging kernel smoothing. The entire collocated set has been split into three latitudinal groups, defined as northern latitudes (30 to 80°N), tropics (30°S to 30°N) and southern latitudes (64°S to 30°S). For each latitudinal group, Figures 5.7.8-11 contain:

> Top panel: The time-averaged VMR profiles of the collocated HIRDLS and validating zonal means, along with their standard deviations and the number of collocated matches.
>
> Middle panel: The time-averaged profile of differences between HIRDLS and the validating instrument, along with the standard deviation.
>
> Bottom panel: The time-averaged profile of relative differences between HIRDLS and the validating instrument, along with the standard deviation.

Also, each panel is encased in a dashed square that delineates the pressure range over which the confidence limits of the validation reference are well known, based on the comments on the validation datasets above. A summary of the systematic error scores is included in Tables 5.7.1 and 5.7.2.

Table 5.7.1: Bias estimates (Jun'05-Jun'06): Daytime NO_2 mean {min to max} relative differences over the indicated pressure range

	HIRDLS vs MIPAS [3-30 hPa]	HIRDLS vs ACE [3-30 hPa]
Northern latitudes	2% {-14 to 26%}	-6% {-24 to 1%}
Tropics	-13% {-33 to -8%}	-8% {-44 to 13%}
Southern latitudes	-13% {-65 to 24%}	23% {7 to 31%}

Table 5.7.2: Bias estimates (Jun'05-Jun'06): Nighttime NO_2 mean {min to max} relative differences over the indicated pressure range

	HIRDLS vs MIPAS [3-30 hPa]	HIRDLS vs ACE [3-30 hPa]
Northern latitudes	1% {-21 to 50%}	-1% {-19 to 24%}
Tropics	-9% {-26 to 22%}	-1% {-15 to 23%}
Southern latitudes	-4% {-31 to 26%}	45% {40 to 48%}

As tables and figures attest, both day and nighttime HIRDLS NO_2 zonal means agree with the correlative ACE-FTS profiles over the 3-30 hPa pressure range to better than 25% over the northern latitudes (30°N to 80°N), and the tropical regions (30°S to 30°N) for nighttime products only. The agreement with MIPAS lies mostly within the 30% confidence level at all latitudes over that pressure range. Above 3 hPa, the daytime HIRDLS NO_2 zonal means appear to be negatively biased by up to 50-100% relative to both MIPAS and ACE-FTS. For pressures between 0.75 and 3 hPa, the nighttime HIRDLS NO_2 zonal means agree to within 30-50% with the correlative data, justifying an extension of the lower pressure limit in this case. However, comparisons below 30 hPa look inconclusive. The daytime MIPAS NO_2 VMR peak looks stronger and higher than observed by either HIRDLS or ACE-FTS. The nighttime MIPAS NO_2 VMR peak looks stronger than HIRDLS, also featuring a band of enhanced NO_2 mixing ratio at about 6 hPa that passes undetected by either HIRDLS or ACE-FTS. Subtropical daytime and nighttime NO_2 values observed by HIRDLS tend to be biased low, a feature that can be traced back to a radiance depression triggered by the Kapton obstruction. Over the southern latitudes (30°S to 64°S), HIRDLS day and nighttime products appear biased high relative to ACE-FTS by about 30%, and biased low relative to MIPAS by about 10% - a difference that lies marginally within the confidence limits of the validating instruments.

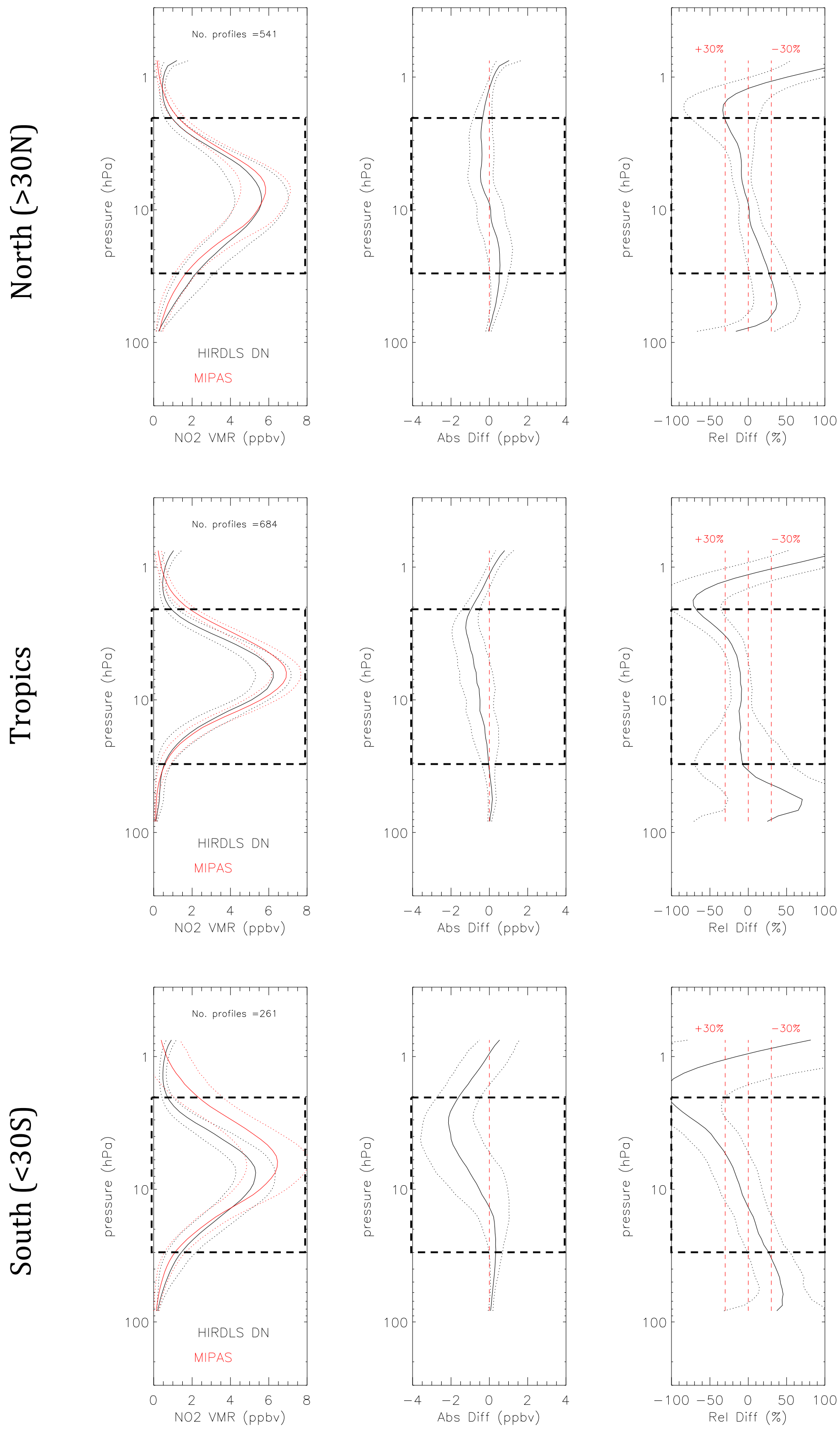


Figure 5.7.8. Systematic errors for daytime HIRDLS vs time corrected MIPAS NO_2 zonal means (Jun'05-Jul'05). Left: mean profiles; Mid: absolute differences; Right: relative differences.

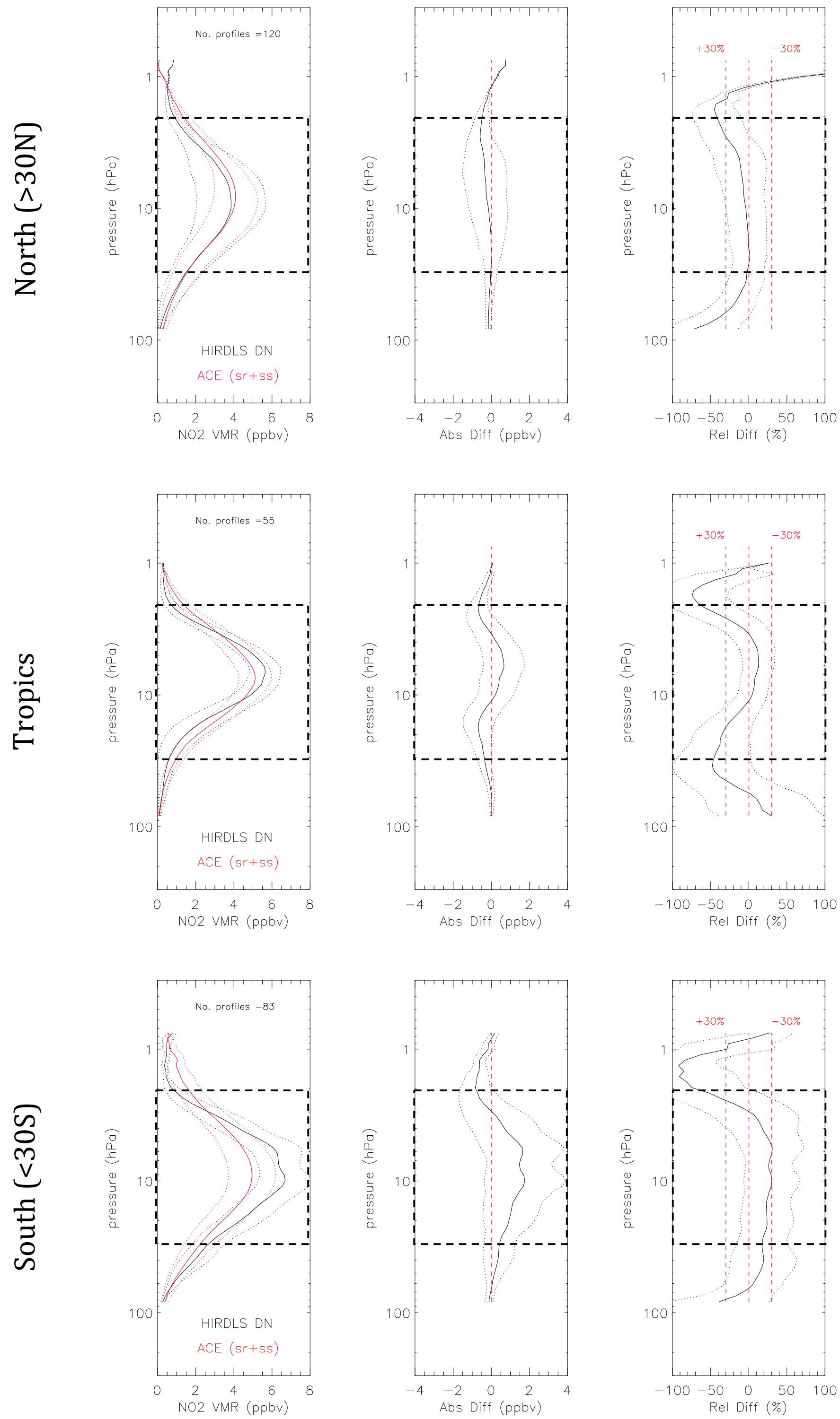


Figure 5.7.9. Systematic errors for daytime HIRDLS vs time corrected ACE-FTS NO_2 zonal means (Jun'05-Jul'05). Left: mean profiles; Mid: absolute differences; Right: relative differences.

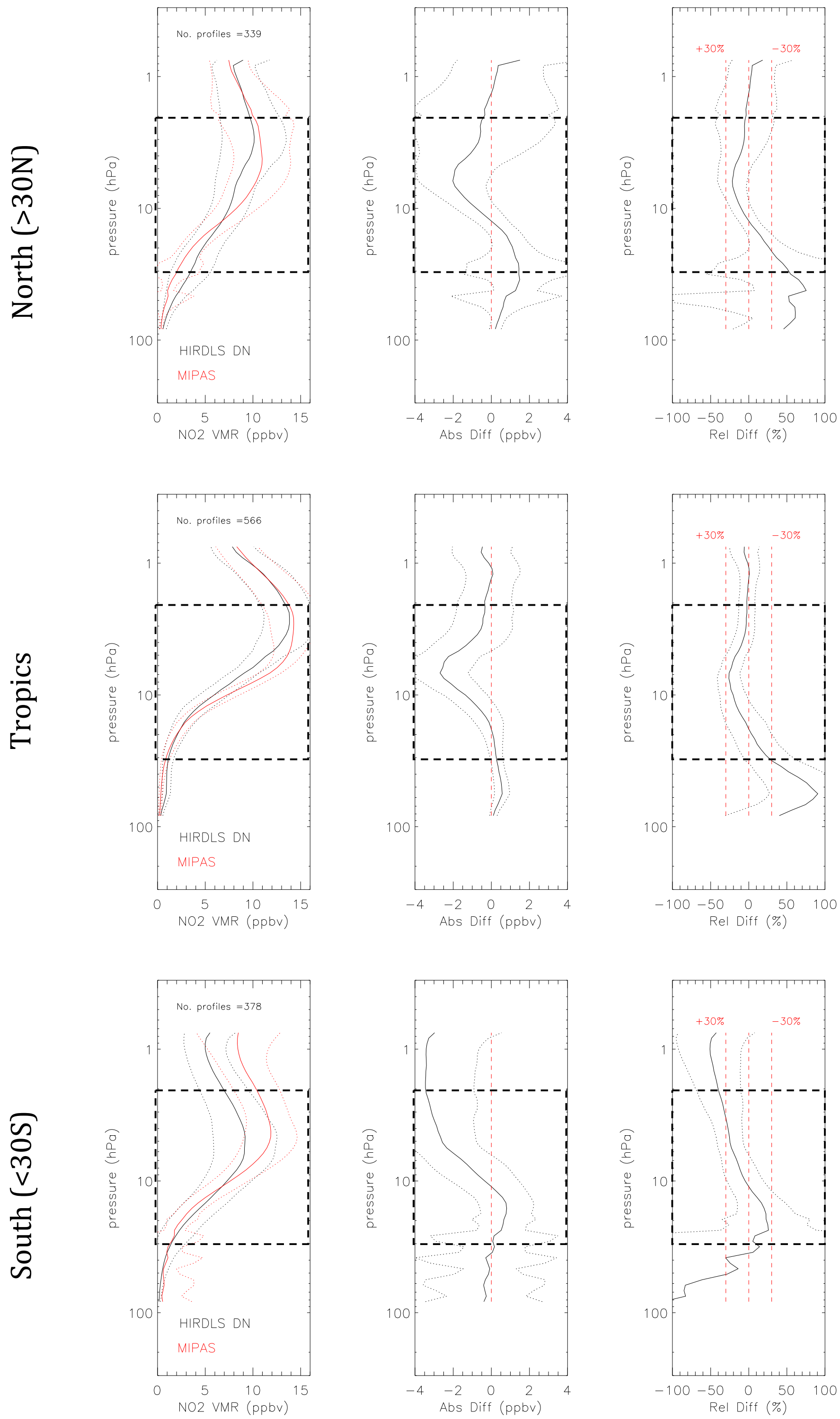


Figure 5.7.10. Systematic errors for nighttime HIRDLS vs time corrected MIPAS NO_2 zonal means (Jun'05-Jul'05) . Left: mean profiles; Mid: absolute differences; Right: relative differences.

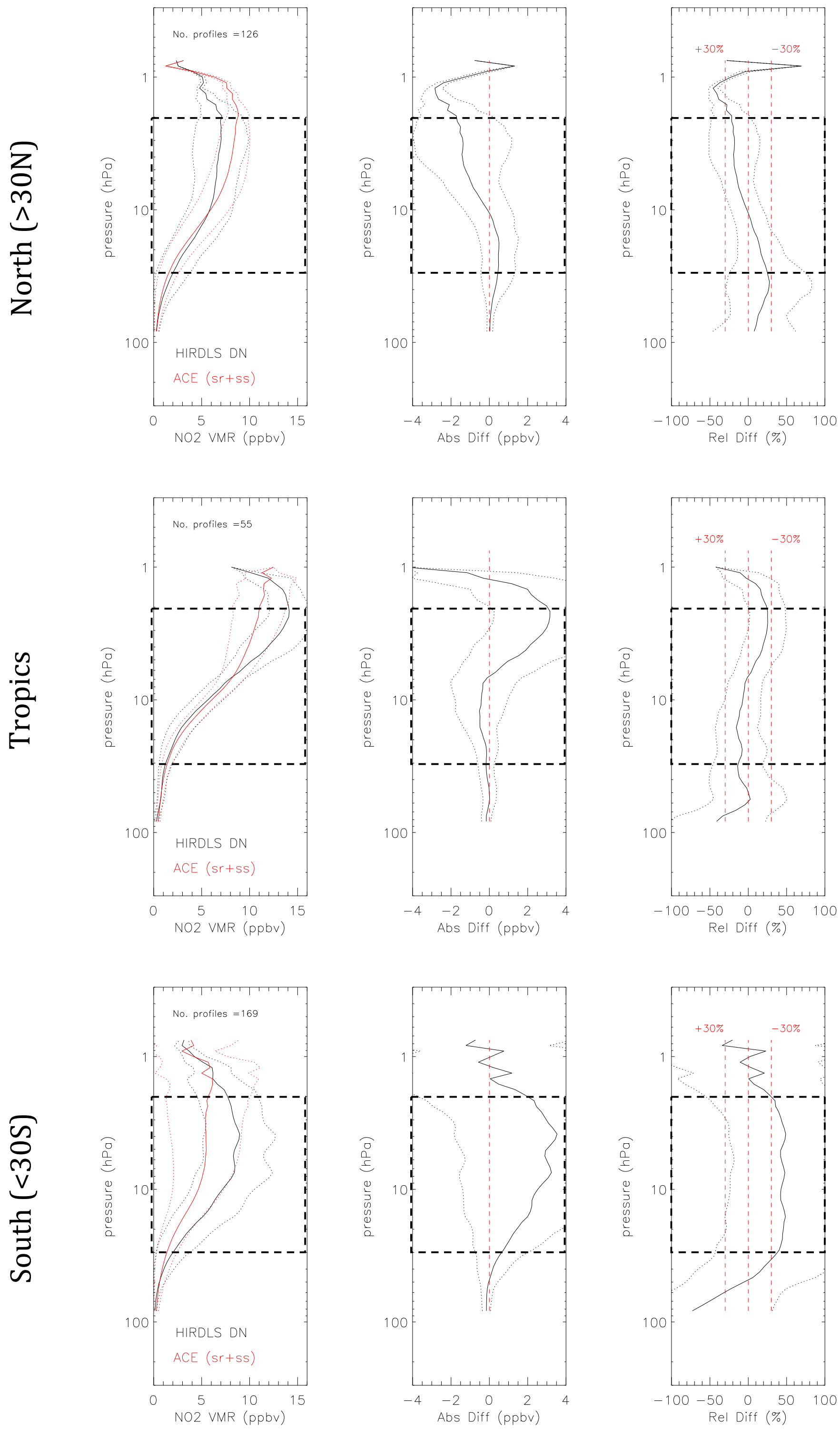


Figure 5.7.11. Systematic errors for nighttime HIRDLS vs time corrected ACE-FTS NO_2 zonal means (Jun'05-Jul'05) . Left: mean profiles; Mid: absolute differences; Right: relative differences.

Observe that these figures of quality are optimistic in the sense that they only apply to the validation period between June 2005 and June 2006. Outside of this period, the accuracy of the HIRDLS NO_2 zonal means tends to deteriorate, with a trend to more negatively biased retrievals towards the end of the mission, and more prominent artifacts (like radiance depression bands or background drift and flicker) that arise from an imperfect removal of the Kapton obstruction.

Summary

The HIRDLS NO_2 zonal means have 1.2 km vertical resolution, a day/night precision of ≤ 0.2/0.4 ppbv and agree to within 25% with correlative ACE-FTS zonal means over the 3-30 hPa pressure range for the northern latitudes (both daytime and nighttime) and the tropical regions (nighttime zonal means only) during the best case period spanning June 2005 through June 2006. The agreement with MIPAS lies mostly within the 30% confidence level at all latitudes over the same pressure range and time period. Outside of the validation period, systematic errors tend to build up and artifacts from an imperfect Kapton correction become more prominent.

5.8 Dinitrogen Pentoxide (N2O5)

Species:	Dinitrogen Pentoxide (N_2O_5)
Data Field Name	N2O5Night
Useful Range:	Nighttime (56.2 – 5.1 hPa)
Screening criteria:	Use with caution: Data outside of the June 2005 – June 2006 period.
Vertical Resolution	1.2 km
Contact:	Maria Belmonte Rivas
Email:	rivasm@ucar.edu
Validation paper	In preparation

General Comments

The daily HIRDLS N_2O_5 zonal means are extracted from the zeroth order zonal coefficient of the synoptic fields estimated by a Kalman filter (as described in Section 4.5) applied to measured N_2O_5 profiles retrieved from down-scans. The zonal means are split into daytime (SZA < 90°) and nighttime (SZA > 100°) products using a latitude grid spacing of 2°. Only nighttime products will be released in Version 6, since reduced N_2O_5 mixing ratios during daytime render these retrievals vulnerable to biases and unsuitable for scientific studies at the present time. The local solar time (LST) of the nighttime zonal means is a function of latitude, as already shown in Figure 5.7.3.

Resolution

The HIRDLS N_2O_5 vertical resolution is approximately 1 km at peak VMR levels, as determined from the full-width at half maximum of the nighttime averaging kernels shown in Figure 5.8.1, gradially decreasing to 2-3 km as the gas mixing ratio approaches zero at the upper and lower ends of the gas profile.

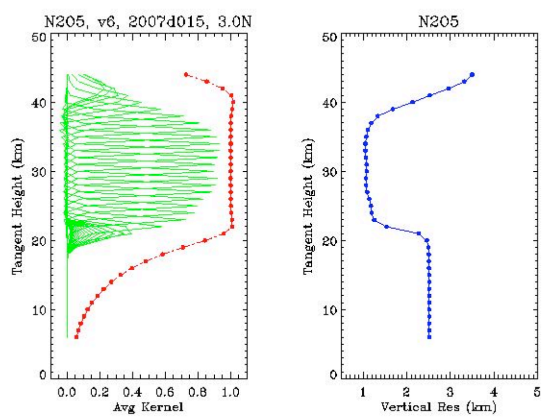


Figure 5.8.1. Averaging kernels (left, green lines) and vertical resolution (right, blue curve) as a function of altitude for nighttime HIRDLS N_2O_5 zonal means.

The red line in the left panel indicates the fraction of information that comes from the HIRDLS measurements; values close to unity mean that there is negligible influence from the a priori. The averaging kernels were calculated for 15 January 2007 at 3°N with a cloud top altitude of 8 km: any latitudinal variations should be small over regions with large signal to noise ratio.

Precision

The estimated precision of the HIRDLS Kalman filtered N_2O_5 zonal mean is displayed in Figure 5.8.2 along with the predicted precision of the raw N_2O_5 profile data. The ratio of raw profile to zonal mean precision is commensurate with the square root of the number of profiles *N* assimilated by the Kalman filter per latitude bin per day (N~32). The estimated precision of the N_2O_5 zonal means is ~0.04 ppbv (5-15%) for the night products.

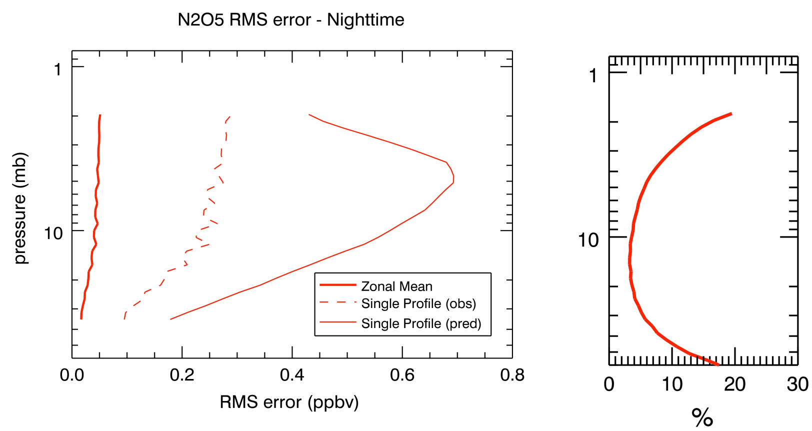
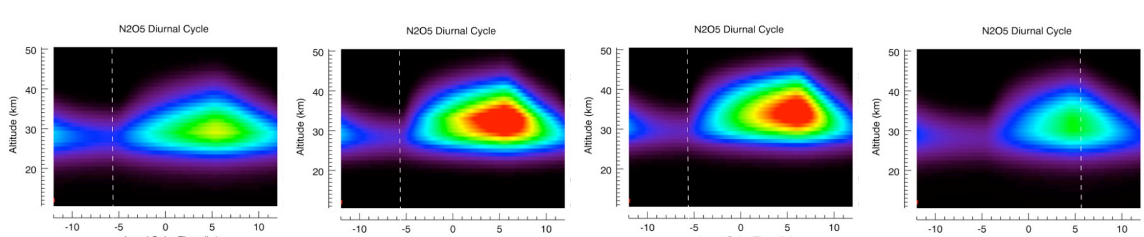


Figure 5.8.2. Estimated precision of the nighttime HIRDLS V6 Kalman filtered N_2O_5 zonal means (thick solid lines) compared with the observed and predicted precision of original profile data (dashed lines and thin solid lines).

Accuracy

In order to arrive at an estimate of absolute bias, the HIRDLS Kalman filtered N_2O_5 zonal means have been compared to independent MIPAS and ACE-FTS datasets. To account for the diurnal cycle of N_2O_5 and the different local observation times of HIRDLS and the validating instruments, a photochemical correction is introduced.

N_2O_5 is in photochemical equilibrium with NO and NO_2, featuring a smooth profile with minimum (maximum) mixing ratios before sunrise (after sunset) and a broad peak at nighttime between 3 and 30 hPa (25 to 40 km) as shown in Figures 5.8.3 and 5.8.4. The photochemical model correction is effected through the ratio of modeled N_2O_5 profiles evaluated at the appropriate latitude (*lat*) and corresponding observation times (*LST, LST_0*), as already introduced in section 5.7.



60N 30N 30S 60S

Figure 5.8.3. Diurnal variation of N_2O_5 (Equinox, March 21st 2005) from ACE photochemical box model

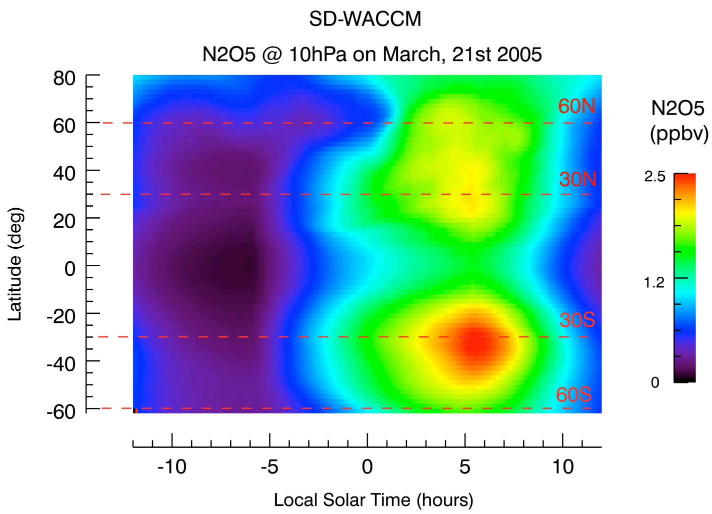


Figure 5.8.4. Diurnal variation of N_2O_5 Equinox, March 21st 2005) from SD-WACCM (pressure level at peak VMR height for day or 10 hPa)

Validation datasets

Spectroscopic measurements of N_2O_5 are difficult due to the presence of interfering species and aerosol in the band that is typically used for retrievals. The altitude range for the ACE-FTS N_2O_5 profiles (Version 2.2, see section 5.7 for more details on this instrument) is from 15 to 40 km and the vertical resolution 3-4 km, with a reported single profile precision of 5% from 20 to 35 km and ~15% elsewhere. The MIPAS N_2O_5 profiles have a vertical resolution of about 4-6 km between 30 and 40 km altitude (6-8 km elsewhere) and a reported precision of 5-35% between 20 and 40 km.

Although there exists a validation paper that performs a critical comparison between the ACE-FTS N_2O_5 profiles and time-shifted MIPAS retrievals [Wolff, 2008], we opted to redo the validation work using the latest MIPAS N_2O_5 release (Version IMK-IAA Version 40). We confirm that the agreement between MIPAS and sunrise ACE-FTS N_2O_5 zonal means (both time-shifted to HIRDLS observation times) lies within 20% over the northern (>30N) and southern (<30S) latitudes within the 4-60 hPa pressure range (20 to 40 km), and roughly within 30% over the tropical regions for pressures between 3-40 hPa. Over the tropical regions and for pressures higher than 40 hPa, MIPAS N_2O_5 profiles are biased low by up to 90% relative to sunrise ACE-FTS zonal means. The time-shifted sunset (SS) and sunrise (SR) ACE-FTS N_2O_5 profiles are in consistent agreement from 4 to 60 hPa over the northern latitudes, but sunset estimates appear to be low-biased by 30-50%

relative to sunrise ACE-FTS and MIPAS profile at all other latitudes, so they will be dropped from the validation dataset.

Up/down-scan agreement

Any preliminary quality test to the Kalman filtered N_2O_5 zonal means should include a comparison of the fields retrieved from its up- and down-scans (see section 5.7). The up/down-scan nighttime N_2O_5 zonal mean differences are displayed in Figure 5.8.5.

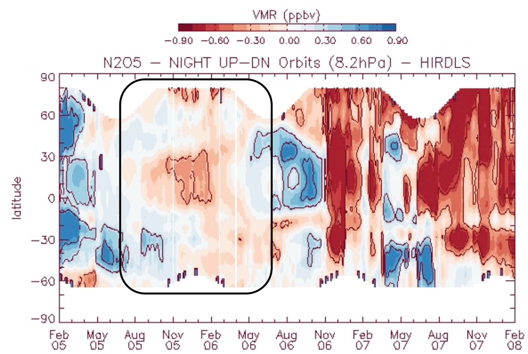


Figure 5.8.5. Internal consistency: up/down-scan differences for nighttime N2O5 zonal means

The combined up/down-scan differences provide a bias estimate of ~ 0.2 ppbv (15% at 8.2 hPa) for nighttime products over the Jun'05-Jun'06 window, which we denote the validation period. Outside of the validation period, systematic errors in the HIRDLS N_2O_5 zonal means can be as high as 70% for VMR peak levels during nighttime, clearly dominating over random errors. Figure 5.8.6 shows a representative "best case" comparison between the N_2O_5 zonal means from HIRDLS, MIPAS and the SD-WACCM model during the validation period on May 4th 2006.

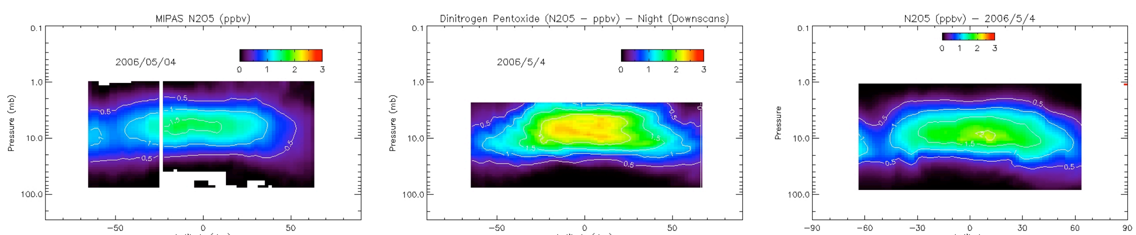


Figure 5.8.6. Sample nighttime N_2O_5 zonal means from MIPAS (left), HIRDLS (center) and SD-WACCM (right) – photocorrected to HIRDLS observation time.

The systematic error analysis that follows is based on the comparison of HIRDLS with MIPAS and ACE-FTS zonal mean observations time-corrected to HIRDLS measurement times and collected over the validation period, from June 2005 through June 2006. The collocation consists of simple latitude matching, with MIPAS and ACE-FTS each having about 14 profiles per latitude bin. The reference profiles have been linearly interpolated to the HIRDLS altitude grid, without averaging kernel smoothing. The entire collocated set has been split into three latitudinal groups, defined as northern latitudes (30° to 80°N), tropics (30°S to 30°N) and southern latitudes (64°S to 30°S). For each latitudinal group, Figures 5.8.7 and 5.8.8 contain:

Top panel: The time-averaged VMR profiles of the collocated HIRDLS and validating zonal means, along with their standard deviations and the number of collocated matches.

Middle panel: The time-averaged profile of differences between HIRDLS and the validating instrument, along with the standard deviation.

Bottom panel: The time-averaged profile of relative differences between HIRDLS and the validating instrument, along with the standard deviation.

Also, each panel is encased in a dashed square that delineates the pressure range over which the confidence limits of the validation reference are well known, based on the comments on the validation datasets above. A summary of the systematic error scores is included in Table 5.8.1.

Table 5.8.1: Systematic error estimates (Jun'05-Jun'06): Nighttime N_2O_5 mean {min to max} relative differences over the indicated pressure range ([5.1-60 hPa] over northern and southern latitudes, [5.1-40 hPa] in the tropics)

	HIRDLS vs MIPAS	HIRDLS vs ACE (SR)
Northern latitudes	**12% {-48 to 43%}**	**4% {-32 to 33%}**
Tropics	**19% {-11 to 58%}**	**12% {-24 to 23%}**
Southern latitudes	**-29% {-82 to 8%}**	**-42% {-140 to -5%}**

As the table above and figures below attest, the HIRDLS nighttime N_2O_5 zonal means agree with the correlative ACE-FTS profiles to better than 30% over the 5.1-60 hPa pressure range over the northern latitudes (30°N-80°N), and over the 5.1-40 hPa pressure range over the tropical regions (30°S-30°N). Within the same pressure range, the agreement with MIPAS appears a bit less satisfying, but always within the 20-30% uncertainty margin sustained by the validating instruments. A remarkable feature arising from the comparison is the conformity between the ACE-FTS and MIPAS references in suggesting that HIRDLS may be slightly high-biased overall (~10%), and severely low-biased at the southern latitudes, particularly above 10 hPa. Another feature would refer to HIRDLS peak N_2O_5 being located lower than either MIPAS or ACE-FTS. Agreement with MIPAS over the northern latitudes may suggest that HIRDLS data remain useful at pressure altitudes lower than 60 hPa.

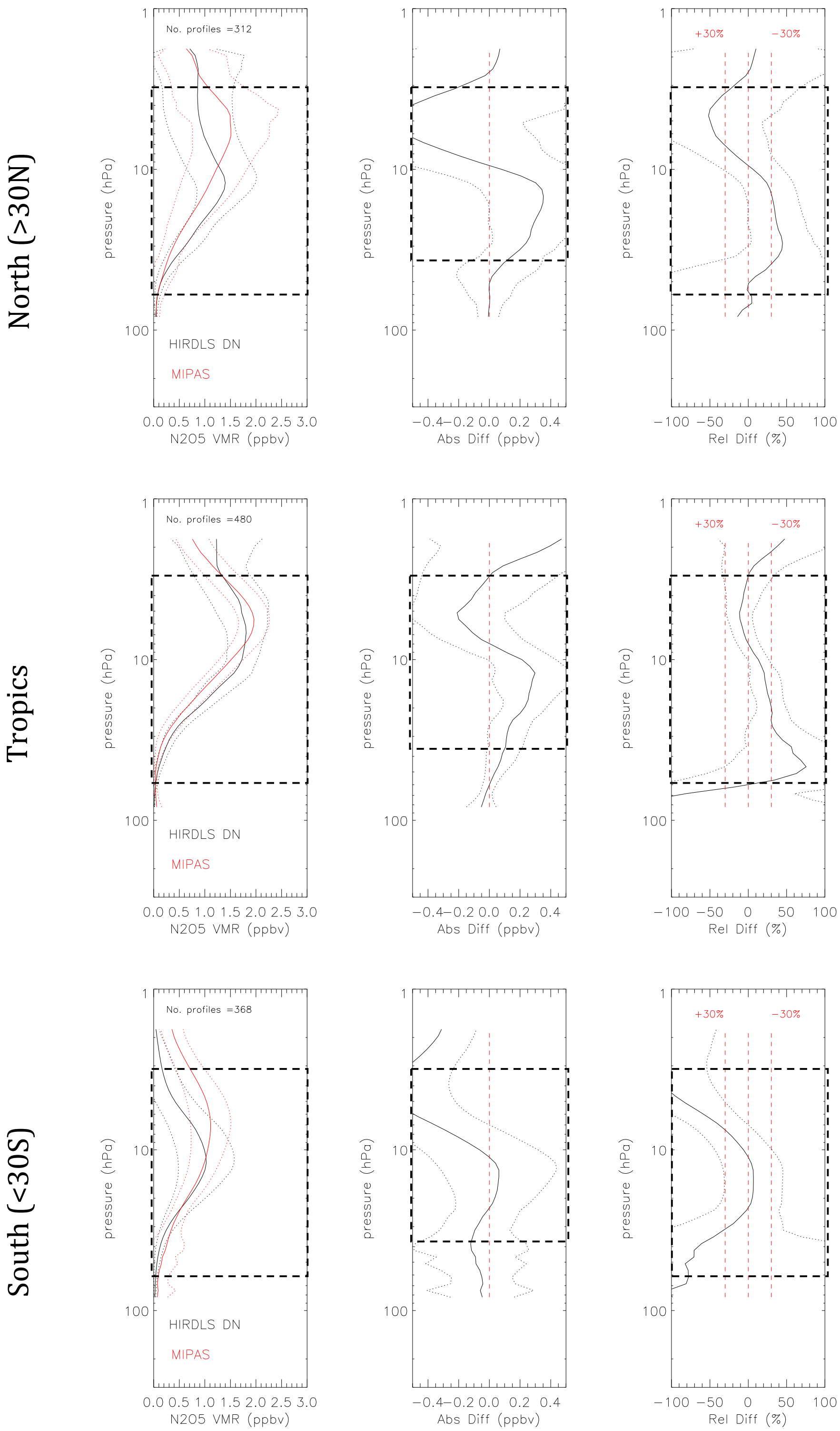


Figure 5.8.7. Systematic errors for nighttime HIRDLS vs time corrected MIPAS N_2O_5 zonal means (Jun'05-Jul'06) Left: mean profiles; Mid: absolute differences; Right: relative differences.

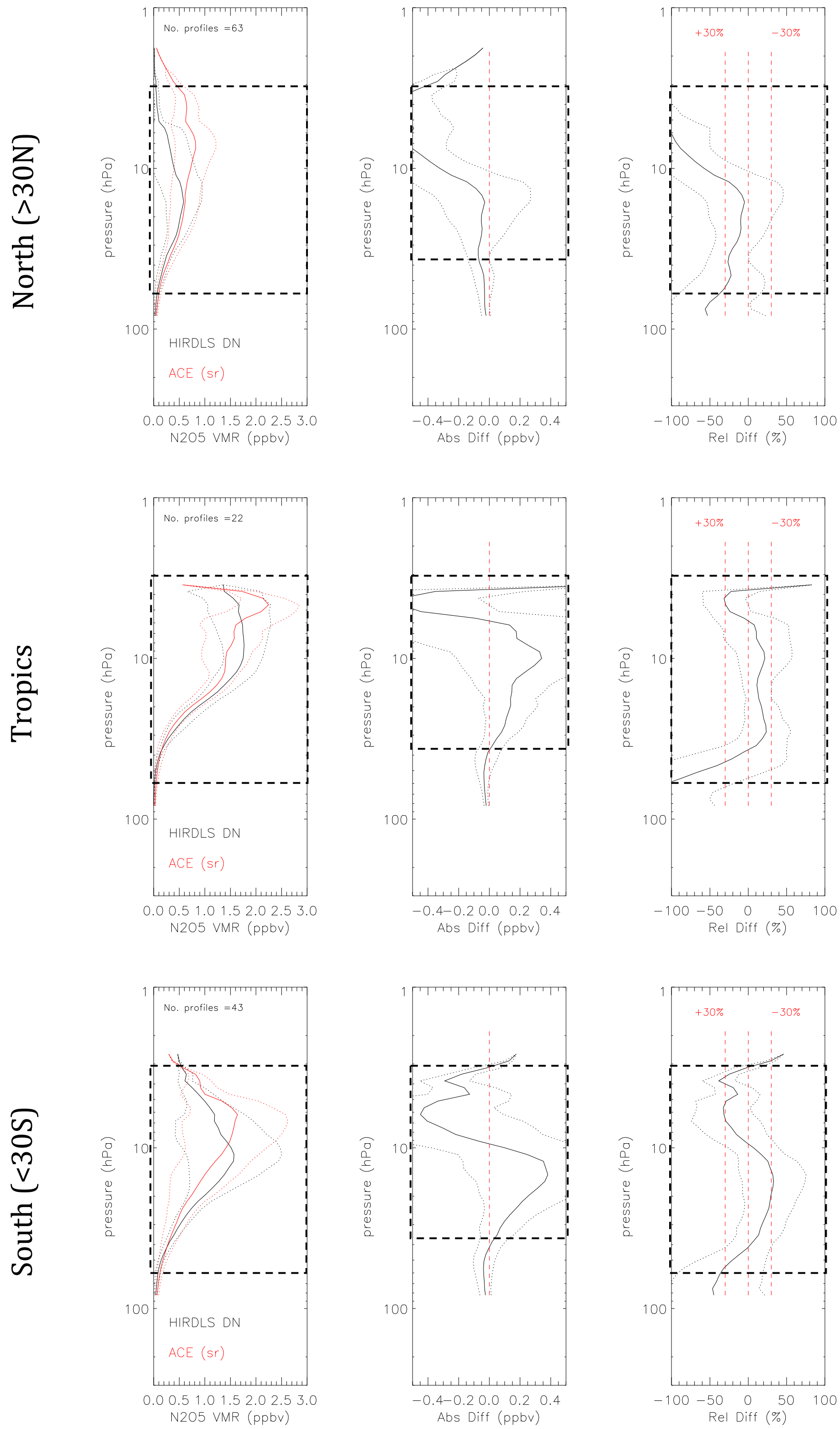


Figure 5.8.8. Systematic errors for nighttime HIRDLS vs time corrected ACE-FTS N_2O_5 zonal means (Jun'05-Jul'06) Left: mean profiles; Mid: absolute differences; Right: relative differences.

Recall that these figures of quality are optimistic in the sense that they only apply to the validation period between June 2005 and June 2006. Outside of this period, the accuracy of the HIRDLS N_2O_5 zonal means tends to deteriorate, with a trend to more negatively biased retrievals towards the end of the mission, and more prominent artifacts (like radiance depression bands or background drift and flicker) that arise from an imperfect removal of the Kapton obstruction.

Conclusion

The nighttime HIRDLS N_2O_5 zonal means have 1.2 km vertical resolution, a precision of ≤ ~0.04 ppbv (5-15%) and agree to within 30% with correlative ACE-FTS zonal means over the northern latitudes from 5 to 60 hPa and over the tropical regions from 5 to 40 hPa during the validation period spanning June 2005 to June 2006, with mean absolute differences generally within 0.2-0.3 ppbv. The agreement with MIPAS is slightly less definite, but within the 20-30% uncertainty margin sustained by the validating instruments. Both validating instruments, ACE-FTS and MIPAS, suggest that HIRDLS N_2O_5 zonal means are severaly low biased (up to 100%) over the southern latitudes, particularly above 10 hPa.

*5.9 Chlorine Nitrate (ClONO2)**

* To Be Supplied

5.10 Cloud Products

Data:	Cloud Top Pressure, Cloud Flags
Data Field Names:	CloudTopPressure, 12.1MicronCloudAerosolFlag
Useful Range:	422-10 hPa
Screening Criteria:	Some false cloud positives are present, z > 20 km
Vertical Resolution:	1 km
Contact:	Steven Massie
Email:	massie@ucar.edu
Validation Paper:	Massie *et al*., [2007] High Resolution Dynamics Limb Sounder observations of polar stratospheric clouds and subvisible cirrus, *J. Geophys. Res*., *112*, D24S31, doi:10.1029/2007JD008788.

General Comments

HIRDLS data files contain cloud flags and cloud top pressures. Details of the determination of cloud top pressures and cloud flags are discussed in Massie et al. [2007].

Cloud flag data is contained in the “12.1MicronCloudAerosolFlag” data variable. Cloud flags are stated at each pressure level when pressures correspond to altitudes between 5 and 30 km altitude. Cloud flag values are 0 (no clouds), 1 (unknown cloud type), 2 (cirrus layer), 3 (extensive Polar Stratospheric Cloud [PSC]), and 4 (opaque). If the cloud flag is nonzero, then this indicates that the radiance at that pressure is measurably different from the clear sky radiance profile. Note that the total number of PSCs is equal to the number of cloud flags with values of either 1 or 3.

Comparisons of clear sky and individual radiance profiles of the various cloud types are presented in Figure 5.10.1. Note that radiance perturbations are substantial for several cloud types, since gas opacity in HIRDLS Channel 6, the 12 μm “infrared window” channel, is very low. Any cloud opacity along the HIRDLS limb-view tangent ray path produces a substantial 12 μm radiance signal.

The cloud top pressure (i.e. the ‘CloudTopPressure’ variable in the archived data file) is determined in the following manner. For a single day’s set of radiance profiles, the clear sky radiance profile for HIRDLS channel 6 is calculated by an iterative technique for several latitude bands. For the first iteration, the average profile, its standard deviation, and associated gradients from 5 to 30 km altitude, are calculated summing over all profiles. For the second iteration, profiles are tossed out of the ensemble average (based on the fact that a cloudy radiance profile deviates from the average curve). New standard deviations and associated gradients are recalculated. The iterative process continues for five iterations.

Note that the HIRDLS focal plane has three columns of detectors. The 12 μm detector is in the middle column, while the three ozone detectors 10-12 are in the first column, and the two columns are separated in distance by ~17 km. Situations arise in which the cloud top structure differs along the 17 km horizontal distance, i.e. a cloud top in the first column can be higher than that in the middle column. Subsequent to the methodology and discussions in Massie et al., [2007], the cloud detection routines now also determine cloud tops in the tropics in the transparent ozone channel 12. The cloud top altitude is assigned to be the higher of the channel 12 and channel 6 cloud top altitudes.

Once the clear sky radiance profile is calculated, we determine the altitude level at which cloud radiance perturbations are first noted. The cloud top pressure (in hPa) is the pressure derived by the operational retrieval on an arbitrary altitude grid with 1 km vertical spacing. The cloud top pressure is determined before the temperature, mixing ratio, and extinction profiles are interpolated unto the standard output pressure grid.

There are some instances in which cloud flags falsely indicate the presence of clouds near and above 20 km altitude, especially at polar latitudes, outside of the seasons in which PSCs are expected to occur. These false identifications occur when radiances become very low in the 20 to 30 km altitude range.

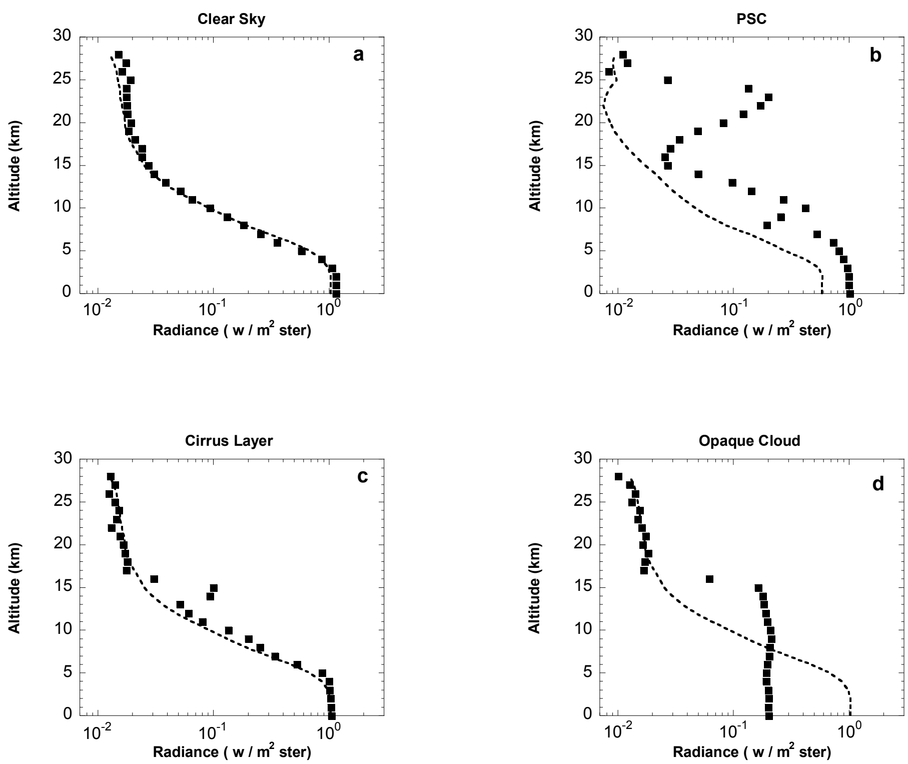


Figure 5.10.1. Four representative Channel 6 (12.1 μm) radiance (single squares) and clear sky average profiles (dotted curves) on January 27 2005, a) clear sky (15.57° N, 216.20° E), b) PSC (68.31° N, 343.41° E), c) tropical cirrus layer (4.32° N, 220.00° E), and d) opaque tropical cloud (16.79° S, 223.72° E) cases. Panels a, b, c, and d correspond to cloud flags equal to 0, 3, 2, and 4, respectively.

HALOE and V6 HIRDLS time averaged cloud top statistics are presented in Figure 5.10.2. The normalized distributions of HIRDLS cloud top pressure data in 2007 and HALOE data from 1998 to 2005 in Figure 5.10.2 have correlations of 0.64 and 0.89, respectively. The large differences in the number of observations of the HIRDLS and HALOE experiments are due to the fact that HALOE was an occultation experiment, while HIRDLS made observations every 15 seconds.

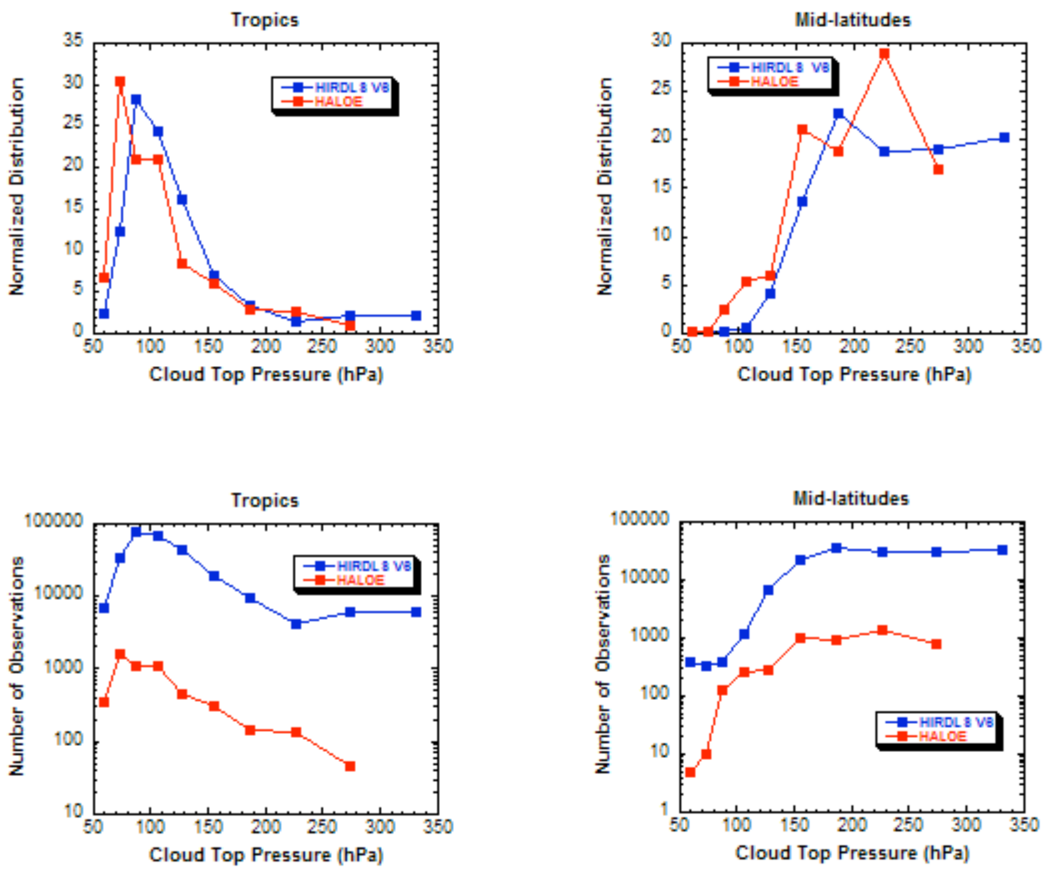


Figure 5.10.2 A comparison of V6 HIRDLS and HALOE cloud top pressure statistics for data in 2007 and HALOE data from 1998 through 2005.

Since the standard gas species retrievals terminate at the cloud top, the frequency of retrieval of gas species will decrease as pressures increase. The fraction of the time for which clouds are absent along HIRDLS limb paths in 2007 is presented in Figure 5.10.3. The latitudinal variation of the cloud free percent frequency is primarily influenced by the location of the tropopause. While the cloud free percent frequency is low at higher pressures, the number of cloud free profiles is still large at higher pressures due to the large number of profiles (~5500 per day) measured by the HIRDLS experiment.

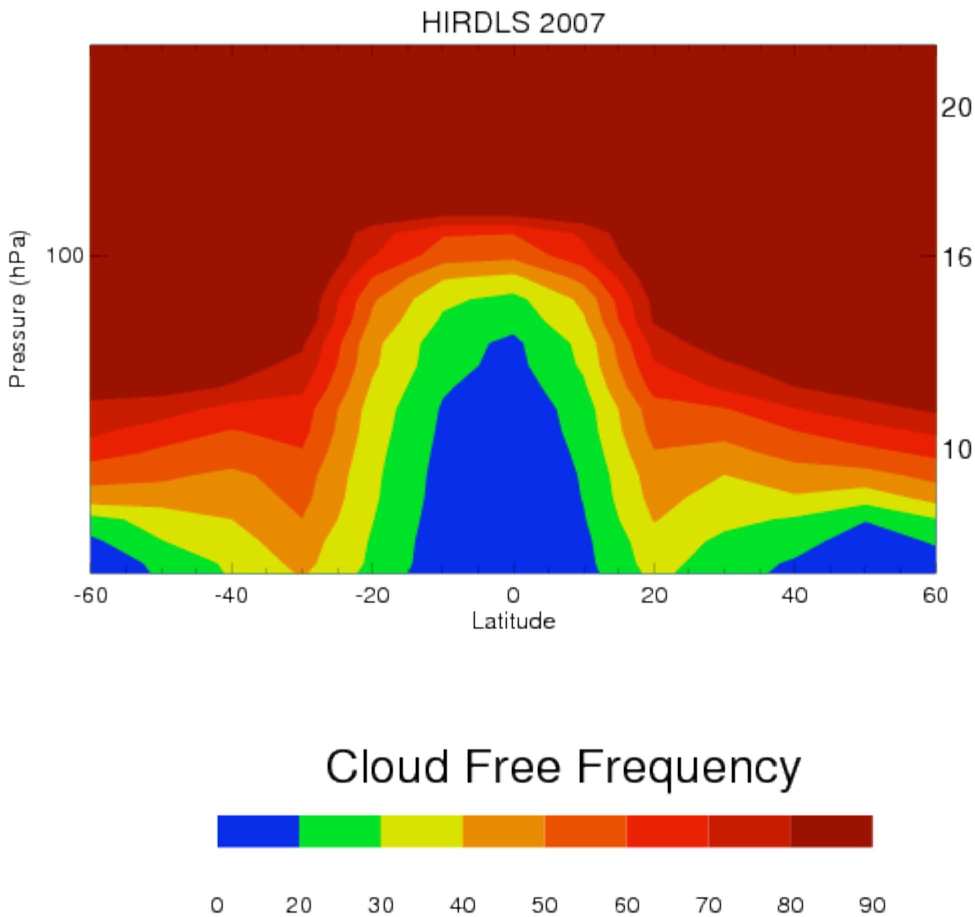


Figure 5.10.3. V6 cloud-free frequency in 2007. All pressures below the cloud top pressure of a single radiance profile are considered to be influenced by clouds. An approximate altitude scale in kilometers is given on the right hand side of the figure.

Figure 5.10.4 presents a comparison of V4 and V6 cloud frequency of occurrence in 2007 at 121 hPa for the four seasons. It is readily apparent that the two frequencies of occurrence are very similar for the two data versions. This figure was created by calculating at each pressure level the fraction of the time that extinction was between 9.0×10^{-4} km^{-1} and 1.0×10^{-2} km^{-1}, the extinction precision was less than the positive value of extinction, and when the cloud flag was nonzero.

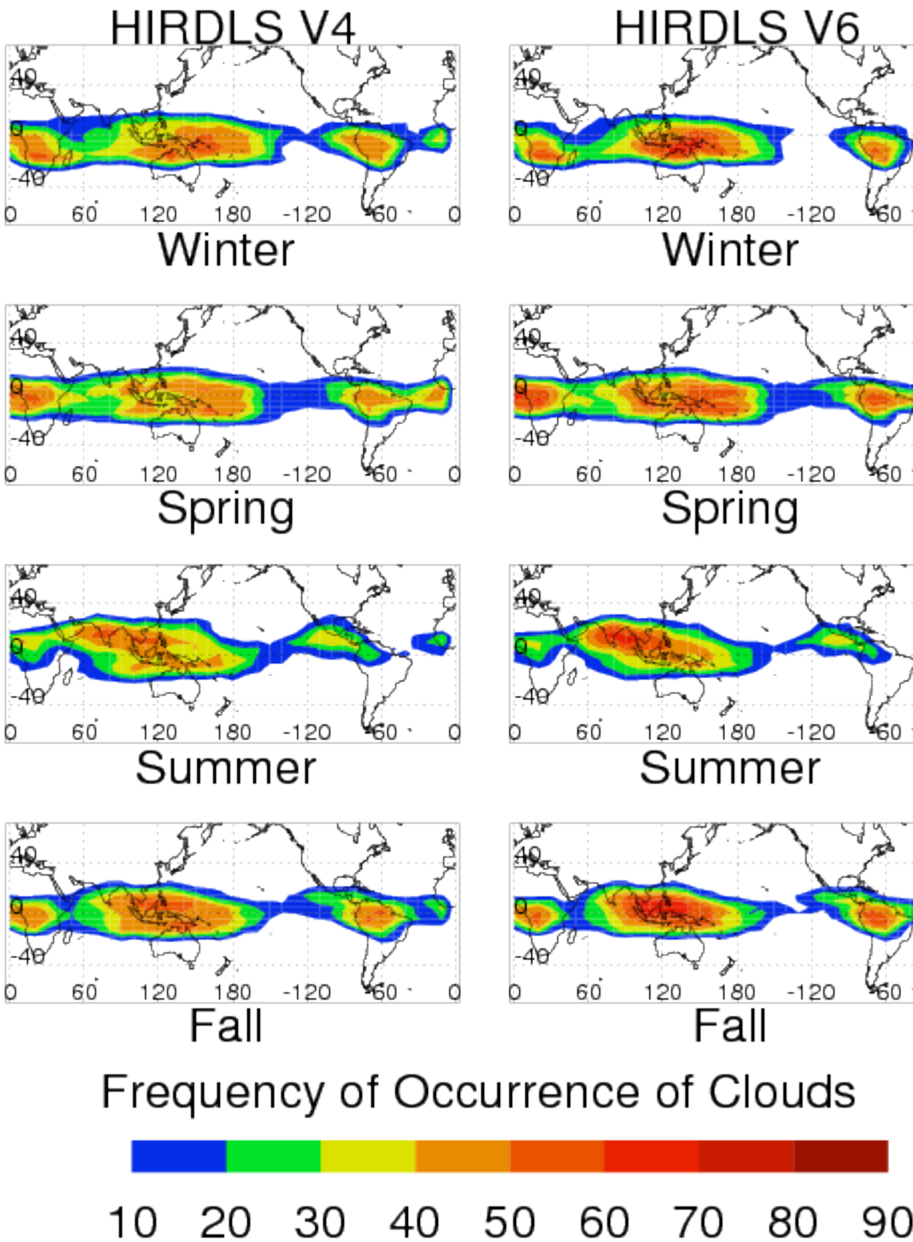


Figure 5.10.4. V4 and V6 cloud frequency of occurrence in 2007 for all cloud types for the four seasons at 121hPa.

Summary

HIRDLS cloud top pressures have been validated by comparing statistics for 2007 with HALOE data from 1998 to 2005. The similarity of the normalized distributions leads to confidence in these values. Comparisons with CALIPSO (not shown) also support these results.

5.11 12.1 Micron Extinction

Data	12.1 Micron Extinction
Data Field Name:	12.1MicronExtinction
Useful Range:	215-20 hPa
Screening Criteria	Use extinction in a qualitative manner Use extinction between 10^{-5} to 10^{-2} km^{-1} Precision/data in 0 to 100% range Clouds are present if the extinction is greater than 9×10^{-4} km^{-1}
Vertical Resolution:	1 km
Contact:	Steven Massie
Email:	massie@ucar.edu

Cloud and aerosol extinction and extinction precisions, in units of km^{-1}, at 12 µm are included in the "12.1MicronExtinction" and "12.1MicronExtinctionPrecision" data fields.

Extinction is archived for pressures between 20 to 215 hPa. Data above and below this range of pressure is flagged as -999 in the V4 and V6 data versions. It is recommended that extinction in the range of 10^{-5} to 10^{-2} km^{-1} be used when the precision is positive from 0 to 100%. Two week (or longer) cross-section (hPa vs. latitude) of zonal mean averages of extinction above the tropopause are recommended when examining the sulfate aerosol extinction in the stratosphere. Due to differences in the V4 and V6 radiance profiles, the V6 zonal averages of extinction become larger than the V4 zonal averages for pressures less than 40 hPa.

The 20 hPa pressure limit allows for inclusion of PSC observations in the archives and was also determined from comparisons of HIRDLS extinction profiles with correlative profiles. Mid-latitude HIRDLS extinction profiles at pressure levels less than 20 hPa increase in value, which is unrealistic. The higher pressure range of extinction (i.e. 215 hPa) was selected due to the fall off of extinction retrieval frequency (when the precision is less than the extinction) at pressures greater than 215 hPa in the tropics and mid-latitudes. Geospatial patterns of time averaged cloud extinction in latitude-longitude maps are coherent at pressures from 215 hPa up to the tropopause.

Since the 12 µm channel radiances are very low (which makes this "infrared window" especially good for detecting clouds), the absolute calibration of the radiances is still problematic. The extinction for the retrieved sulfate aerosol in the stratosphere is larger than correlative measurements (i.e. HALOE extinction zonal averages and University of Denver size distributions, converted to extinction profiles via Mie calculations) by a factor of ~2 for the V4 data, and more so for the V6 data at pressures less than 40 hPa. For this reason the data should be used in a qualitative manner, whereby the extinction data is used to indicate sulfate (low) extinction versus cloud extinction in a relative manner. Cloud extinction at 12 μm is present when the extinction is greater than approximately 9 x 10^{-4} km^{-1} (i.e. the cloud extinction threshold determined previously by Mergenthaler, et al., [1999], based upon analyses of the 12 μm extinctions of the Cryogenic Limb Array Etalon Spectrometer (CLAES) experiment on the UARS platform).

Figure 5.11.1 presents seasonal latitude-longitude graphs of V6 and V4 HIRDLS extinction for 2007 at 121 hPa. The extinction averages are similar to those obtained by previous solar occultation experiments, with maxima over the maritime continent, Africa, and South America. Monsoon dynamics influence the distribution of clouds over India during summer, while deep convection during winter produces high cloud frequencies over the maritime continent.

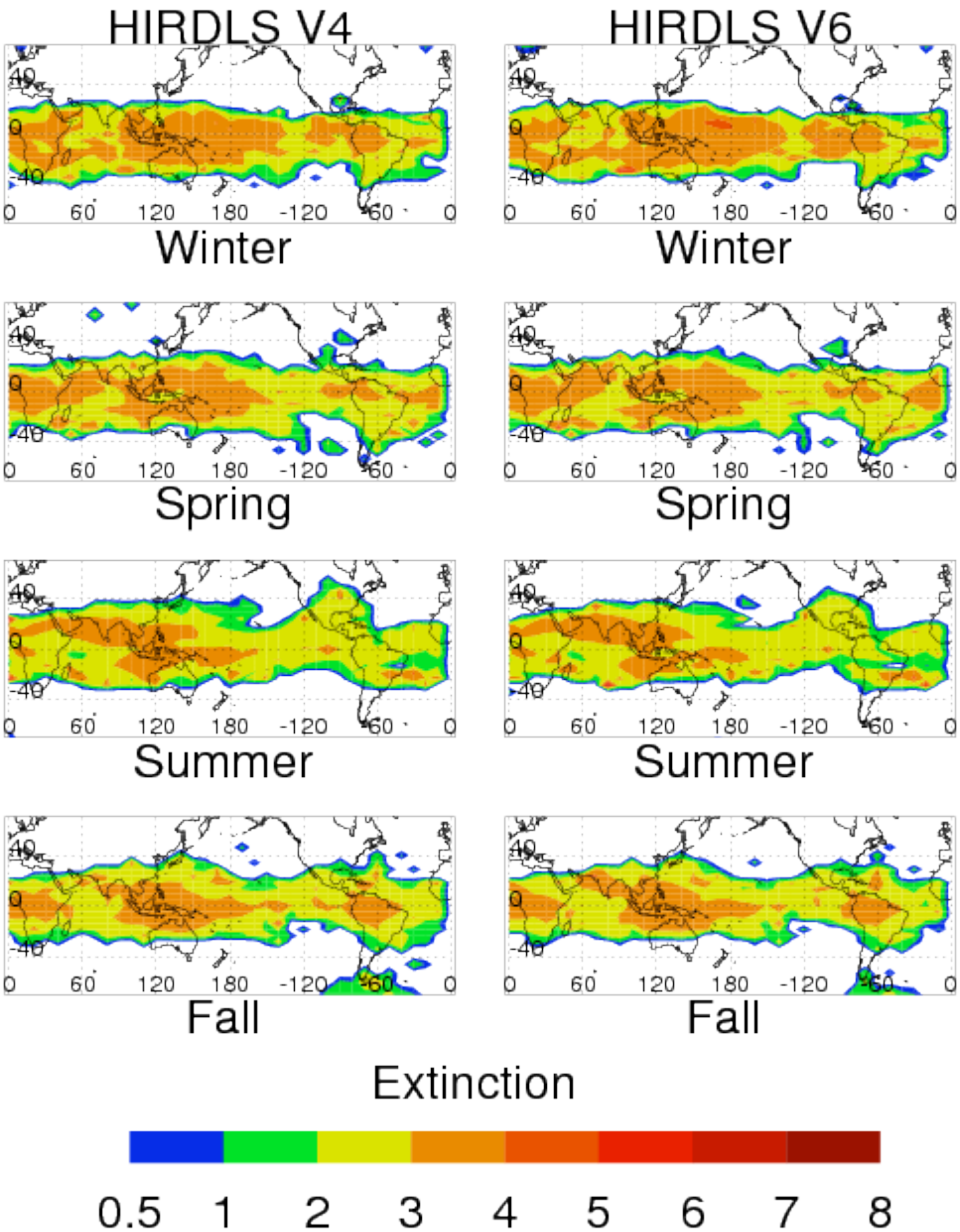


Figure 5.11.1. V6 and V4 HIRDLS seasonal extinction at 121 hPa during 2007. Extinction values are in units of 10^{-3} km^{-1}.

Summary

Extinction values appear to be too high by a factor of 2 or so. It is suggested that values in the range 10^{-5} to 10^{-2} km^{-1} be used in a qualitative way when the predicted precision values are positive, between 0 and 100%.

5.12 Geopotential Height (GPH)

Species:	Geopotential Height (GPH).
Data Field Name:	GPH Raw GPH
Useful (vertical) Range:	1000 - 0.01 hPa* * HIRDLS pointing plus a priori temperatures for p >383 hPa
Vertical Resolution:	Since GPH involves integrating over HIRDLS Temperatures, GPH is reported every pressure level, so a bit better than 1km. See section 5.1.
Contact:	Lesley Smith
Email:	lsmith@ucar.edu

Precision

The observed precision is estimated in the way described in Section 5.0. GPH values on a pressure level for 12 consecutive profiles are taken at times and locations in which geophysical variation were expected to be low. Data used were in the tropics at equinoxes and solstices for years 2005-2007. The standard deviation of their departures from a linear detrending line was determined, and the average of the 10 smallest values was calculated. These results are presented in Figure 5.12.1, where the solid line indicates this observed precision. The dashed line is the precision predicted by the GPH algorithm incorporating the uncertainties in the input parameters.

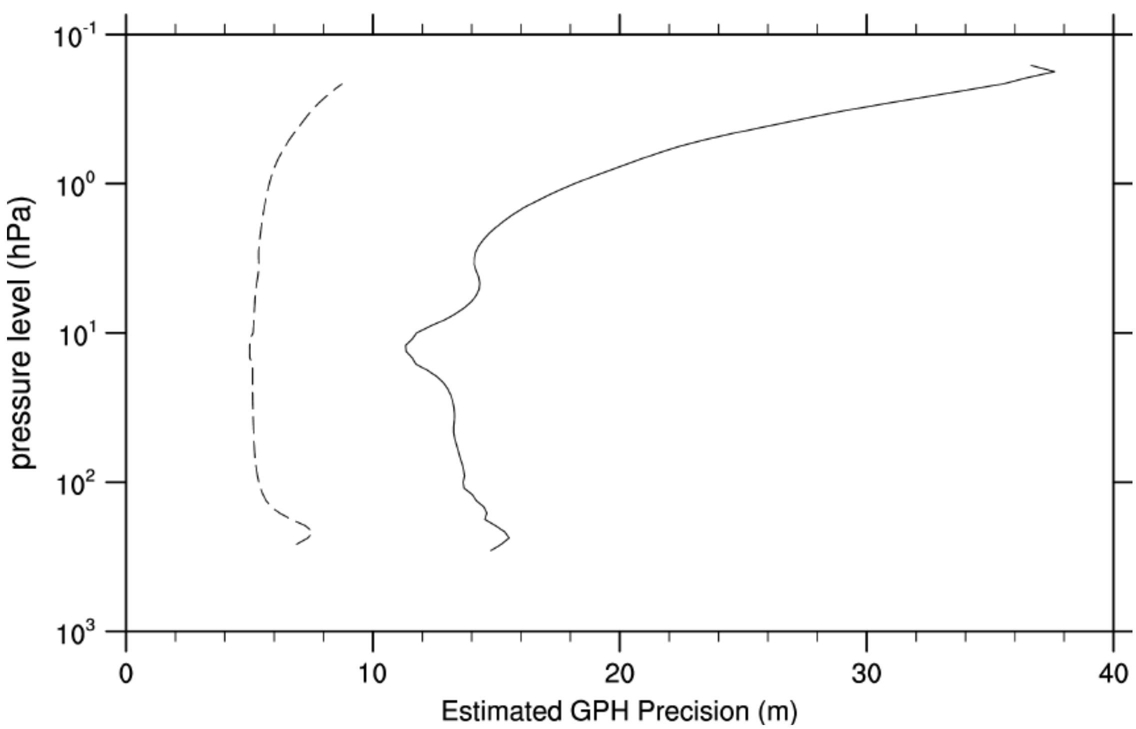


Figure 5.12.1: Estimated precision of HIRDLS V6 GPH (solid line), compared with precision prediction by the GPH algorithm (dashed line).

Accuracy

HIRDLS GPH's have been compared to several data sets in an effort to determine the extent and magnitude of any bias. In Figure 5.12.2 we see HIRDLS GPH binned by latitude, averaged over 2005-2007 minus ERA-Interim, NCEP/NCAR Reanalysis, and GEOS-5 data at sample pressure levels 10hPa and 100hPa. HIRDLS GPH has systematic differences with the other fields, the reasons for which we do not know at this time.

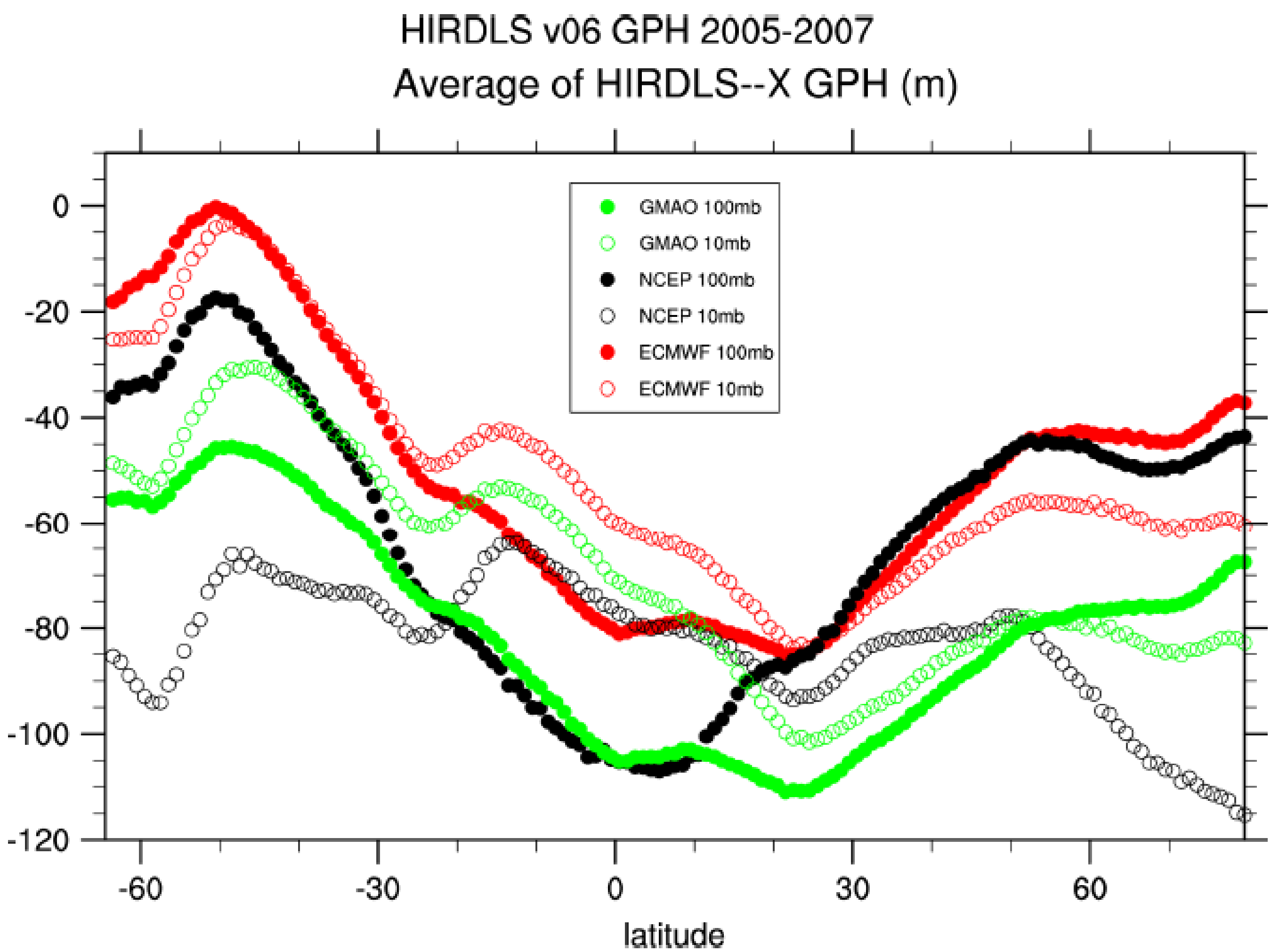


Figure 5.12.2: Differences between HIRDLS and several other calculations of GPH.

Future Improvements

We are investigating the low bias of HIRDLS GPH (see accuracy statements above) and plan to resolve this issue.

Summary

The GPH is based entirely on spacecraft pointing data and HIRDLS temperatures, and it has the corresponding 1 km vertical resolution. From the troposphere to the stratopause the precision is ~ 15 m, above which it increases to 35 m at 0.1 hPa. The bias in the GPH difference from -63° to the equator is < 90 m at 100 hPa, and <60 m at 10 hPa. The bias in difference from the equator to 80° is < 65 m at 100 hPa, and < 35 m at 10 hPa when compared to conventional analyses based on assimilation of meteorological data. These NH gradients correspond to differences in geostrophic winds at 60° of ≤ 0.5 m/s at 100 hPa, or ≤ 0.3 m/s at 10 hPa. Similarly, winds in the SH would differ from those based on the assimilated data by < 1 m/s at -60°.

6.0 HIRDLS Level 3 Gridded Data Products

Daytime stratospheric NO_2 columns

Field Name: NO2DayColumn

Partial columns of daytime NO_2 amounts were calculated over pressure altitudes ranging from 1 to 56.2 hPa. The HIRDLS daytime NO_2 mixing ratios were gridded each day on a 2° x 2° latitude-longitude grid using the first 3 zonal waves of the Kalman filtered fields. These were then vertically integrated into column amounts C_{NO2} (molec/cm^2) at each grid point as:

$$C_{NO2} = k \sum_{i=0,\dots,N} [NO_2]_i \, \Delta p_i$$

Where $[NO_2]_i$ is the mean NO_2 VMR across a layer of pressure thickness Δp_i (in Pa), and $k = 0.1 \cdot N_A/M_{NO2}$ with N_A being Avogadro's number (molec/mol) and M_{NO2} the molecular mass of NO_2 (g/mol). The HIRDLS daytime partial columns have an estimated precision of ~5% (< 1×10^{14} molec/cm^2). Figure 6.0.1 shows a sample map of HIRDLS daytime stratospheric NO_2 columns for December 21st 2005.

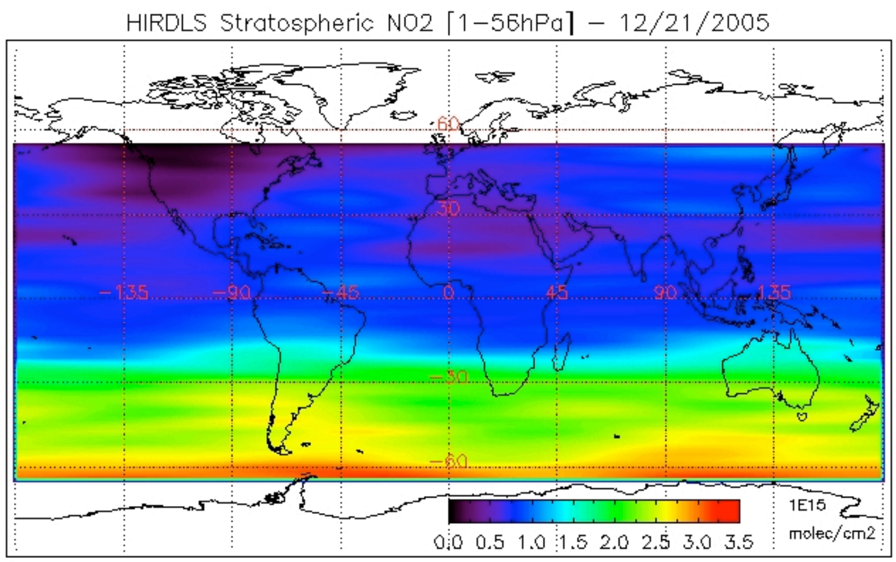


Figure 6.0.1. Daytime stratospheric NO_2 column on December 21st 2005

The accuracy of the HIRDLS daytime stratospheric NO_2 columns has been verified against correlative and time-shifted partial columns obtained from MIPAS zonal mean profiles and the SD-WACCM model for the time period spanning June 2005 through June 2006, and the results are shown in Figure 6.0.2 and 6.0.3.

The agreement between the HIRDLS and MIPAS partial NO_2 columns over the validation period is better than 30%, in line with the accuracies reported for the zonal mean profiles in the Section 5.7. There appears to be a clearly persistent bias pattern in the MIPAS and SD-WACCM comparisons: the HIRDLS partial NO_2 columns seem to be biased low by up to 30% over the subequatorial band that extends from 0 to 30S, where NO_2 column amounts are the lowest, while HIRDLS partial columns seem to be biased high at higher latitudes, where NO_2 column amounts reach their highest values. This effect is likely associated to an imperfect radiance calibration.

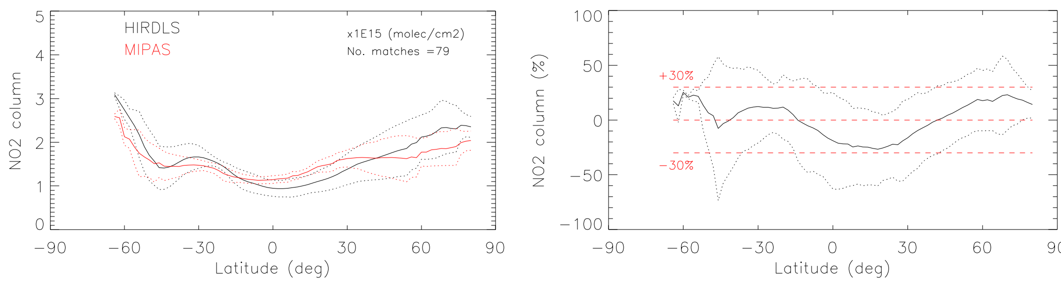


Figure 6.0.2. Systematic error: Daytime stratospheric NO2 columns (HIRDLS vs time-corrected MIPAS) (Daily zonalmeans Jun'05-Jul'05)

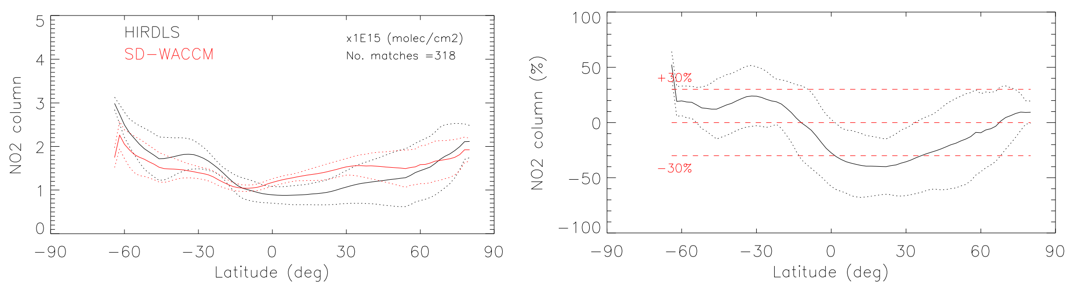


Figure 6.0.3. Systematic error: Daytime stratospheric NO_2 columns (HIRDLS vs SD-WACCM) (Daily zonalmeans Jun'05-Jul'05)

Figure 6.0.4 shows a latitude-time cross-section of NO_2 partial columns estimated from HIRDLS observations and the SD-WACCM model over the validation period. HIRDLS observations tend to measure lower NO_2 amounts during the northern winter than predicted by the SD-WACCM simulation. Unfortunately, the density of MIPAS observations during this period is very low and will not lend itself to further inference. Otherwise, seasonal features seem to be in overall good agreement.

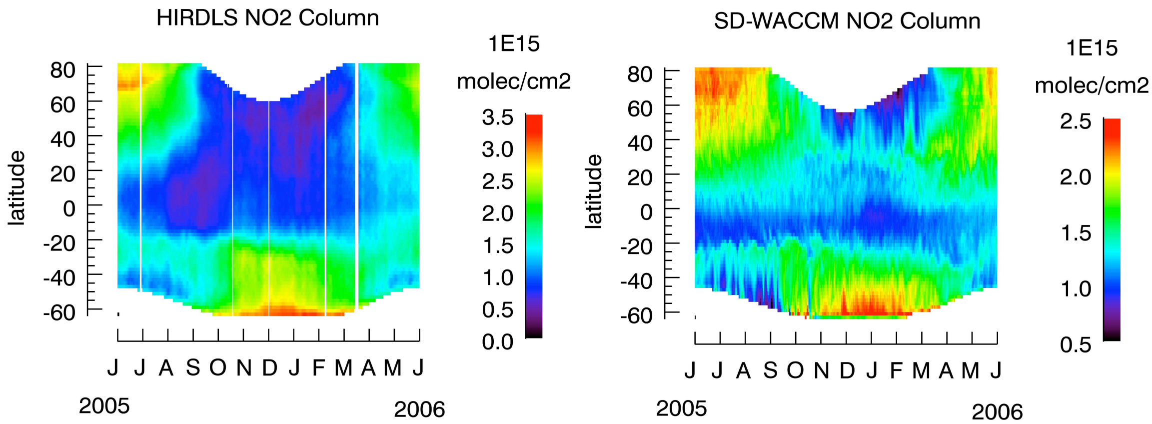
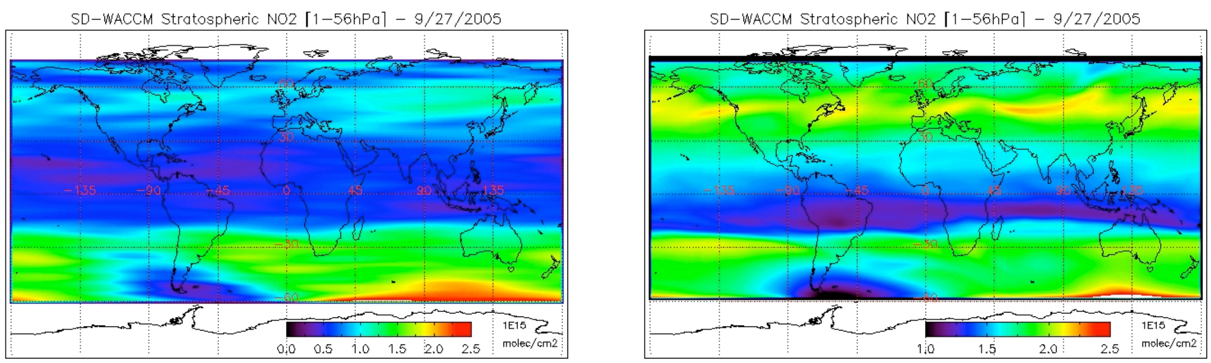


Figure . 6.0.4 Latitude-time cross-sections of daytime stratospheric NO_2 columns: HIRDLS (left) and SD-WACCM(right)

The longitudinal structure captured by the zonal wave expansion of HIRDLS columns is qualitatively verified against SD-WACCM results and shown in Figure 6.0.5. The modeled NO_2 column amounts are extracted from daily SD-WACCM snapshots collected at 00:00 UTC (midnight at Greenwich). To eliminate the diurnal NO_2 variability, we use the quasi-conserved combination of [NO] + [NO_2] + 2[N_2O_5] VMRs, and assuming a maximum NO_2 mixing ratio about 2 hours after sunset, apply a longitudinally flat local solar time correction as a function of latitude, altitude and day of the year.



HIRDLS **SD- WACCM**

Figure 6.0.5 Longitudinal structure in daytime stratospheric NO2 columns: HIRDLS (left) and SD-WACCM(right)

Summary

The HIRDLS daytime stratospheric NO_2 columns from 56.2 to 1 hPa have a precision of 5%. Differences from MIPAS and the SD-WACCM vary with latitude, but are everywhere within 30%. The longitudinal structures captured by the HIRDLS NO_2 partial column amounts seem realistic.

7.0 Data File Structure and Content

Contact: Vince Dean
Email: vdean@ucar.edu

Warning for IDL users: Due to internal changes within the HDF5 library used to create V5 and V6 data, IDL must be upgraded to at least 7.1 in order to read the HIRDLS V5 and V6 data.

HIRDLS Level 2 and Level 3 data are stored in the HDF-EOS5 format and the fields are as described in the _HDF-EOS Aura File Format Guidelines_ document[2]. These data files can be read via C/C++ or Fortran using either the HDF-EOS5 or HDF5 library. HIRDLS has developed both an IDL routine "get_aura" and a set of Fortran90 routines to access the HIRDLS Level 2 data. Both of these routines are available for download via the HIRDLS web site, http://www.eos.ucar.edu/hirdls/data/access.shtml. The routines can also be supplied via email upon request.

Starting in V5, it is also possible to read the HIRDLS data via netCDF calls using the netCDF4.1 and later libraries. Even though the data was written using HDF-EOS5, the netCDF4.1 and later libraries can read the HIRDLS V5 and V6 data files.

Users should obtain the pre-compiled HDF5 library for their operating system, if possible, otherwise source code is also available from the HDF Group (see http://www.hdfgroup.org). These are prerequisite in order to compile the HDF-EOS5 library (see http://www.hdfeos.org/). Both libraries are needed to fully access the Aura HIRDLS data files. For additional help contact the GES DISC at help-disc@listserv.gsfc.nasa.gov or telephone 301-614-5224.

Level 2 Files

Each HIRDLS Level 2 file contains one day's worth of data and contains all species that HIRDLS measures. A number of the fields are filled completely with missing values until correction algorithms are refined for these species. For users who require only a subset of the HIRDLS species, the GES DISC has the ability to subset data before distributing it to users. Contact the DISC directly for more information on this service.

Individual HIRDLS data values for a product are stored in fields labeled with the species name (see the appropriate section above for the exact Data Field Name). The estimated precision of each data point is a corresponding field named *Species*Precision (for instance, Temperature and TemperaturePrecision). Two additional fields for each species, *Species*NormChiSq and *Species*Quality, are both filled with missing for V5 and V6. CloudTopPressure does not have Precision, NormChiSq or Quality fields.

There are two time fields in the HIRDLS data file, *Time* and *SecondsInDay*. *Time* is stored in TAI time (seconds since the epoch of 00.00 UTC 1-1-1993). This time includes leap seconds and can cause problems with simplistic conversions. For this reason, HIRDLS is also storing *SecondsInDay* which is seconds since midnight of the data day. Leap seconds do not pose a problem when using this field. Note that the first data point may be negative which indicates a time stamp before midnight. This is the case for scans which span a day boundary.

Level 3 Data Products

As of V6, HIRDLS will be releasing two new gridded data products. One will be a zonal average and the other will be a partial column. Each product will have its own data file format and is described below. Both are gridded using the Kalman mapping procedure.

The Kalman filter approach used by HIRDLS is an extension of the process described by Remsberg, et al., [1990]. In this application, the data is run forward and backwards twice through the data, iterating on internally calculated covariance statistics and using the estimate to update the nearest pair of latitude grids from each data point. The number of points used to update the coefficients at each latitude is stored in the "DataCount" field. If this value is negative, its absolute value indicates the number of days to measured data. The Precision value is an rms estimate of how close the field represented by the coefficients comes to the data.

Level 3 Zonal Average Files

HIRDLS is introducing a new zonal average data product with V6. This file is written using the HDF-EOS Zonal Average library. There are two files, each of which spans the entire HIRDLS mission; one contains the daytime NO_2, while the other contains the nighttime NO_2 and N_2O_5, with one set of latitude gridded values reported each day/night.

Level 3 Gridded Partial Column

The HIRDLS L3 partial column product is written using the HDF-EOS Grid library. This is a single file containing daily latitude/longitude grids of the partial column products. For V6, only the NO_2 day product is being released.

[2]http://www.esdswg.org/spg/rfc/esds-rfc-009/ESDS-RFC-009.pdf/view

8.0 Algorithm Changes

The HIRDLS version number appears in the file name. The GEOS-DISC identifies the versions by “collection number”, 001 through 006.

HIRDLS Version	GES-DISC Collection Number	Changes
2.00	001	[Baseline]
2.01		Modified to process Scan Table 22
2.02.07	002	Modified to process Scan Tables 30, 13, 22 and 23
2.04.09	003	Modified to include more precise geo-location, updated cloud detection, updated calibration constants, and bug fixes.
2.04.19	004	Added new products: CFC11, CFC12, 12.1 micron aerosol extinction. Implemented updated open area fractions, improved cloud detection and out-of-field correction. Added correction for instrument-spacecraft alignment (equivalent to 2 km shift).
5.00.00	005	Includes packet checksum check; decreases tangent pt. altitude by 250 m; changes radiance scale factors and adds offsets; uses NoiseFac3 for radiance error spectrum, consistent with the latest Open Area Fraction (OAF) values (12/19/2008); incorporates 4/30/08 deoscillation Empirical Orthogonal Function (EOF) values; has +4-2 interpolation for el. angle tie-on; corrects C++ de-oscillator, adjusts alt. range that the boresight must cover to allow processing of ST30; corrects descaling/scaling of rad. errors; uses GEOS-5.1.0 for T radiance adjustment (v24), LOS gradient correction, and T a priori; corrects OrbAscFlag; adds capability to selectively adjust radiances

HIRDLS Version	GES DISC Collection Number	Changes
5.00.00 (con't)	005	by channels; adds OrbitNumber and SpacecraftDayFlag fields to HIRRADNC file; radiance adj. done on all channels except 7, 8, 9 (i.e., HNO3 and CFCs not adjusted); looks for clouds at lower altitude if too many negative radiances; uses toolkit 5.2.15; upgrades to Fortran compiler 10.1.015; releases GPH as new product; reduced output pressure levels from .001 to .01; includes option for using GEOS O_3 and H_2O for a priori; adds OrbitNumber as a field in the output files; can now retrieve H_2O using channels 18 and 20 separately; capability to use 72-level GEOS data; applies geoid correction for GPH calculations; adds new Raw and Smoothed GPH calculations; includes capability to adjust input a priori errors at/below cloud tops or 10 km, whichever is higher; reduces T and O_3 a priori errors at these levels to 2k and 75%, respectively; radiance and retrieval ranges are now specified in altitude instead of pressure; T is retrieved to 120 km; number of diverged retrievals (dropouts) is substantially reduced, especially for T; improves lower mesospheric T retrievals;
V6.00.00	006	Updated radiance error value; removes radiance error bandpass reduction; uses WAACM93 / MLS v3.33/Mozart for contaminants; corrected gamma_evalue; incorporated the latest GPH algorithm; incorporated up-scan 2x2 (no substitution) kapton correction scheme; incorporated the new deoscillation 25-fcn EOF files and algorithm (single window fitting for atmospheric EOFs and ST23 EOF set selection); uses radiance adjustment file v26 cycle 6

GES DISC HIRDLS Version	Collection Number	Changes
6.00.00 (con't)	006	(lower top level in radiance adjustments, and no adjustments for channels 15, 16, 17, 18, 20); incorporated changes in L2 algorithm and new L3 algorithm to output daily zonal means of day/night NO_2 and N_2O_5 as well as NO_2 stratospheric columns; producing monthly means of Ice Water Content (IWC).

9.0 References

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